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Education
in the age of the AI

Young Minds
beyond AI

Interview
Doris Reiter

AI-inquiry
cycle

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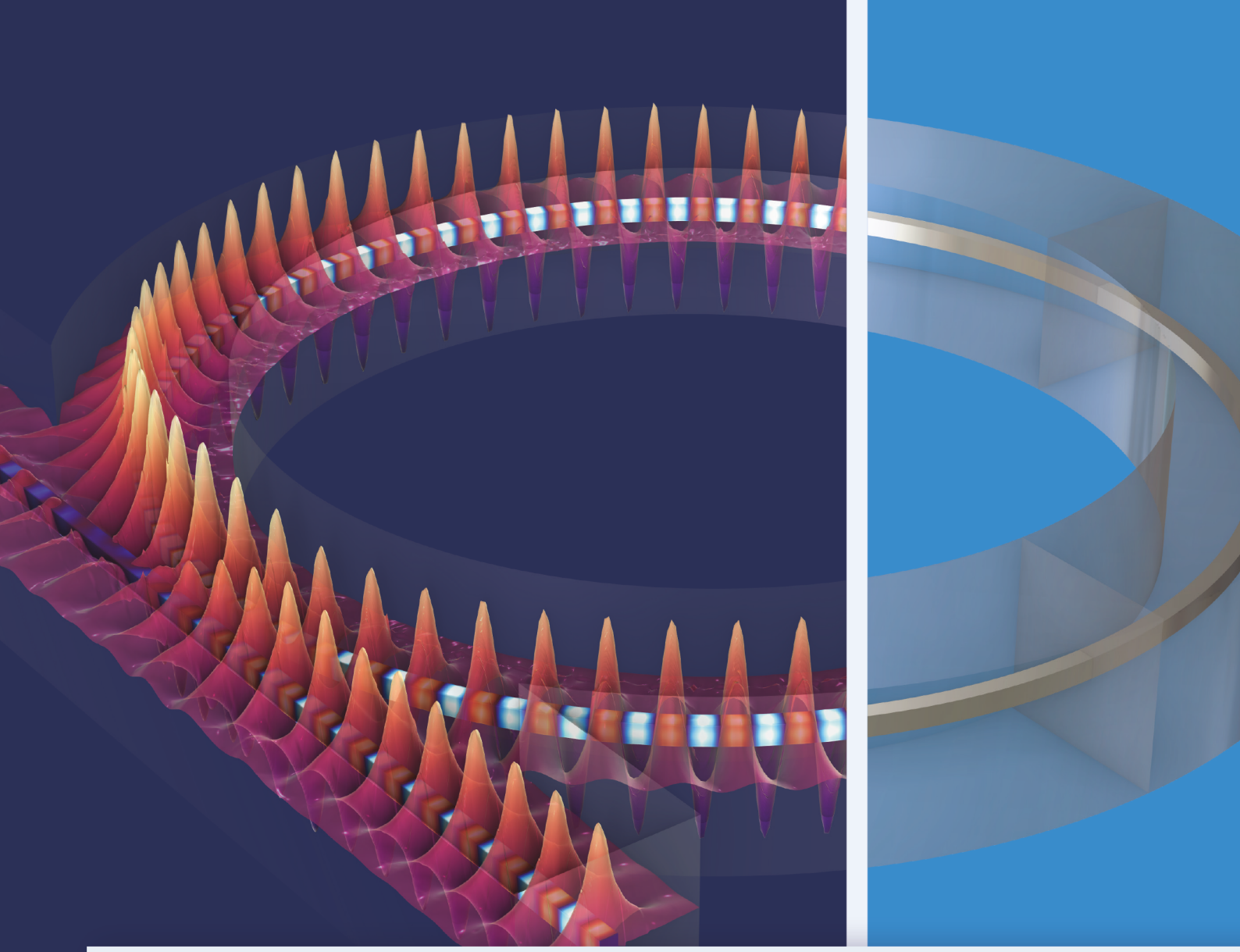

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Cover picture: Collaborative team interaction with AI-based circuit board interface. (© iStockPhoto).

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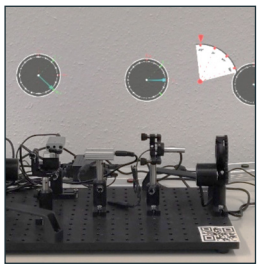
Generative AI will change the way physics is taught and assessed



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[EPS EDITORIAL]

Beyond automation: the limits of artificial intelligence in physics education

DOI: https://doi.org/10.1051/epn/2026201

The rapid development of artificial intelligence (AI) has ignited debate about its role in education, particularly whether it can meaningfully substitute for human teachers. Contemporary AI systems can generate extensive sets of exercises, provide immediate and detailed feedback, and adapt explanations to suit different levels of student understanding. For many learners—especially those who benefit from repetition and incremental reinforcement—such capabilities may rival, or even exceed, the support offered by an average teacher, particularly within the constraints of limited classroom time and large student groups. At first glance, this appears to present a compelling case for adopting AI as a substitute for human instruction.

However, this conclusion warrants careful qualification when one considers the broader aims of education, especially in a discipline such as physics. Education extends beyond the transmission of information and the correction of errors; it also involves the cultivation of intellectual dispositions. Human teachers play a crucial role in fostering motivation, stimulating scientific curiosity, and developing students' capacity for judgment and analytical reasoning. Effective teaching entails not only explaining what is to be understood but shaping how students come to understand. This includes encouraging conceptual thinking, confronting misconceptions, and guiding students through the often-non-linear process of scientific inquiry.

Artificial intelligence, despite its sophistication, remains limited in this regard. While it can simulate dialogue, generate probing questions, and scaffold problem-solving processes, it does not possess genuine intentionality or intellectual curiosity. It lacks the capacity to model the lived experience of discovery that is central to scientific learning. Moreover, it may be unable to sustain student motivation and engagement, thereby increasing the risk of passive learning.

These limitations are particularly significant in physics education, where deep understanding often depends on intuition, conceptual restructuring, and the ability to connect abstract principles to physical reality. Such capacities are rarely developed through repetition alone; they require active engagement, and often the influence of a teacher who can inspire confidence and curiosity. The substitution of human interaction with machine-mediated instruction, even when technically efficient, may therefore lead to an impoverished form of learning if not carefully balanced.

It follows that artificial intelligence is more appropriately understood as a powerful complement to, rather than a replacement for, human teachers. AI excels in the personalisation of practice, the reinforcement of procedural knowledge, and the provision of immediate feedback. Human teachers, by contrast, remain uniquely capable of cultivating the intellectual virtues that underpin meaningful learning: curiosity, critical thinking, and disciplined reasoning. The principal risk in over-reliance on AI is not merely a decline in instructional quality, but an increase in passivity, whereby students become recipients of solutions rather than active participants in the construction of knowledge.

This concern echoes a much older philosophical insight. More than three hundred years ago, in his "Discours de la méthode, pour bien conduire sa raison et chercher la vérité dans les sciences" René Descartes emphasised the importance of intellectual autonomy, urging that one should "never accept anything as true" without clear and distinct understanding, and to avoid both haste and prejudice in judgment. Such a principle underscores the necessity of active reasoning in the pursuit of knowledge—an ideal that cannot be fully realised through passive interaction with even the most advanced technological systems.

In conclusion, while artificial intelligence may rival or exceed average teachers in narrowly defined instructional tasks, it cannot fully replicate the broader pedagogical role of the teacher, particularly in physics education. The enduring value of human educators lies not only in their ability to convey knowledge, but in their capacity to shape the intellectual character of their students. As AI continues to assume responsibility for routine aspects of instruction, the distinctly human elements of teaching—enthusiasm, curiosity, and the ability to inspire—will become not less important, but more so. ■

Mairi Sakellariadou,
EPS President

Young Minds beyond AI

Carmen Martín Valderrama and Damian Rodríguez – DOI: https://doi.org/10.1051/epn/2026202

Artificial intelligence (AI) is rapidly becoming part of the educational landscape. With tools such as ChatGPT, DeepSeek, Gemini, Perplexity or Claude, just to mention a few of them, students can get instant explanations, summarise texts, or check solutions with immediate feedback.

▲ FIG. 1: Workshops examples of YM sections of Messina and Porto.

As these tools become more and more powerful, the traditional way of teaching and learning, usually centred in contents and competences, is being further and further challenged. The sophistication of the AI models is now able to address physics problems, explain and reproduce mathematical demonstrations or write down scripts for specific tasks in almost any programming code. In this context, one could wonder how we can adapt our way of teaching and learning physics to go beyond what AI already offers.

For Young Minds (YM) members, AI is a great tool to have quick responses to doubts, obtaining fast orientation on problems or getting the job done when writing tedious code. These tasks facilitate the way in which contents can be addressed in a lecture, which potentially would leave soon more time to develop other competences through further practical experimentation, peer-to-peer activities or service-learning. These different approaches to formal education are the keystone of the activities that the YM Programme has been performing in cities all around Europe and North Africa during the last sixteen years.

Take workshops, for example. They are one of the most repeated YM activities. Just as an example, in Figure 1 we can see some picture of the workshops "Light and new scientific frontiers: from theory to applications" (Messina) and "Quantum Day@PT" conference (Porto). These workshops bring together researchers, students and professionals creating a common ground for knowledge exchange, deep conversations and interdisciplinary learning. But what makes these workshops powerful is not just the content itself, it is the interaction. A mentor noticing confusion and rephrasing an explanation. A spontaneous discussion between participants. A moment of collective insight when something finally "clicks". These are subtle, human dynamics that cannot be pre-programmed. Even if AI can simulate an experiment or explain a concept, it cannot read the room, adapt in real time to group energy nor create the shared excitement of discovery.

Other type of activity that YM sections regularly organise are public events as lectures, science cafés, and outreach events. These are not just about explaining the concepts, as a generative AI could do, but about creating dialogue between physicists and society, making science visible and approachable and inspiring curiosity in unexpected audiences. A live event has a unique atmosphere, with the unpredictability of audience questions, the charisma and personality of the speaker, and the collective experience of learning something new together. We can "feel" the atmosphere of these kind of outreach events just by looking at the pictures of Figure 2, where we

▼ FIG. 2: Novi Sad YM section outreach event.

▲ **FIG. 3:** Image of the podcast "L'habitació" from the YM section form the Autonomous University of Barcelona, and of the local TV of Valladolid where the YM section from Valladolid, "Physics League", participated explaining different experiments.

can see the event Novi Sad YM section (Serbia) organized dedicated to the promotion of the aerospace engineering and space program. AI can provide answers, but it cannot recreate the atmosphere that makes these events memorable.

In addition, many YM groups produce podcasts and media content to communicate physics beyond academic environments, as the YM section form the Autonomous University of Barcelona does with their podcast "L'habitació", where they interview scientist and researchers in Catalan (which also adds value to their culture and gets to a different public). Some of them even appear in the local TV!! As the YM section from Valladolid, "Physics League", who showed and explained different physics experiments to a very broad public. These two examples are included in Figure 3. What makes these formats compelling is not just the information, but the human voice behind the personal stories of researchers, their doubts, failures, and motivations, and the diversity of paths into physics. Listeners connect not only with the content, but with the people behind it. An AI-generated explanation may be clear, but it lacks lived experience, authenticity and emotional nuance. These are precisely the elements that make science communication meaningful and relatable.

As we have seen from the previous examples, hands-on workshops, public events and social media content directed to either specific or general public are powerful types of strategies that form the core of Young Minds activities. They complement the quick and impersonal access to knowledge that AI offers by putting the focus on experimentation and real interaction with other people. Indeed, perhaps, the most important contribution of YM sections is creating community by doing science. Through their activities, Young Minds Sections create spaces where students feel comfortable asking questions, early-career physicists share advice and individuals realise they are not alone in their struggles, as one can easily realize by taking a look to Figure 4. This sense of belonging is critical, especially in a field that can often feel abstract and demanding and high rate of mental health problems within the student and early researcher communities. AI can support learning, but it cannot mentor, empathise nor build lasting human relationships. And yet, these are often the factors that determine whether someone continues in the physics career or not. We are sure that AI becomes more present in education, it will certainly reshape how knowledge is accessed and processed. But it will not replace the need for human interaction, inspiration, and community. ■

▼ **FIG. 4:** Pictures of the YM groups of Caserta and Catania

We still have way to go, interview with Doris Reiter

– DOI: https://doi.org/10.1051/epn/2026203

We asked Prof. Dr. Doris Reiter, research group leader in theoretical solid-state physics at the Technical University Dortmund and Organizer of the Outreach Project QuanTour, to tell us something about her choices and her career. Doris Reiter received last year EPS Emmy Noether Distinction in recognition of her groundbreaking contributions to theoretical photonics and quantum technology, her transformative leadership and innovative outreach.

Why did you choose physics?
After school, I had a clear idea of what I didn't want to study, which helped narrow things down. From the remaining options, physics stood out. I think I was looking for a real challenge, and physics certainly offered that. I was fascinated by Star Trek, environmental questions, and nuclear physics. Ending up in solid-state and quantum physics wasn't part of a grand plan, but looking back, I couldn't be happier with where I landed.

What is the most rewarding aspect of your career and what difficulties did you encounter?
Receiving the Emmy Noether Distinction is deeply rewarding, because it reflects my scientific achievements. At the same time, it also acknowledges the effort I have put into building networks and contributing to the scientific community. In my everyday work, the most satisfying moments are when something suddenly makes sense. When it just clicks, and you know you've understood something.

My career didn't start out with a strong network or good mentoring. On top of that, I had close colleagues who actively worked against me. I still feel the effects today, as we are often judged by our previous achievements. I think, as a community, we greatly underestimate the impact of networking power. In addition, as a female physicist, I still feel that it takes more effort to win people over. And in a group of a dozen people, it only takes one to spread doubt. That alone can be enough to make things significantly harder.

What are your recommendations to encourage diversity?
This is a complex question, because it touches on so many different aspects. I support quotas, because I believe that without them, real change does not happen. Open conversations about diversity are also essential, not only to normalize the topic but to raise awareness that there is still a long way to go.

In addition, we need structural changes that go beyond just discussions about starting a family or securing permanent positions. Evaluation criteria and hiring practices also need to evolve, because that is where many of the hidden barriers remain.

What is your take on work-life-balance?
I always say that health should be *a priori*ty, both physical and mental. It saddens me to see so many, especially older colleagues, who are overworked and dealing with serious health problems. I think life is a marathon. Maybe it feels good to be ahead for the first 30 or 40 years, but I wonder whether that really balances out if the later years are cut short. Maybe I will see this differently when I am older, but right now I try to look after myself so that I can keep going in a sustainable way. I also try to pass that mindset on to my students. ■

Petra Rudolf,
Chair of the EPS Equal Opportunities Committee.

BiBB: Bringing STEM Expertise into the Heart of Governance

– DOI: https://doi.org/10.1051/2026204

Across Europe, physicists and other STEM researchers frequently express concern that major policy decisions on climate, energy, technology and health are made with too little scientific expertise at the table.

Yet, paradoxically, very few STEM MSc students, PhD graduates, and postdocs see public administration or politics as realistic, intellectually satisfying career paths. In the Netherlands, we created the *Bèta in Bestuur & Beleid* (BiBB – "STEM for Governance and Policy") initiative from the bottom-up to change exactly that. We hope that sharing our experience will stimulate discussion among STEM communities in other countries facing similar challenges and perhaps encourage the development of comparable initiatives.

Founded in 2021, BiBB is a national, interdisciplinary network that brings together members from multiple universities, ranging from PhD candidates to faculty members. It is supported by the wider Dutch STEM ecosystem, including NWO, the Dutch Research Council, and the deans of science and engineering faculties.

At the core of BiBB is a simple idea: building a career pipeline from research into governance. The initiative offers inspiration sessions at universities, an annual national career day for MSc and PhD students and postdocs (with 150 participants, and which has been oversubscribed every year), and an intensive week-long summer school with senior policymakers and civil servants. The aim is to demystify public-sector work, show its intellectual challenge, and give early-career researchers a concrete sense of what it means to serve in ministries, advisory councils, parliament or local government.

The BiBB summer school, first held in 2025, is emblematic of this approach. The 30 participants worked on real policy cases with leaders such as Robbert Dijkgraaf and Eppo Bruins (both physicists and former Dutch Ministers of Education, Culture and Science) and Laura van Hazendonk, who combined her PhD training in chemistry with being a member of the provincial council of Noord-Brabant. Under their guidance, the participants developed professional skills that are rarely taught in STEM curricula: how public institutions work, how to navigate political timelines, how framing works and how to communicate complex issues under pressure. A sustained alumni network supports participants as they move into public-sector roles. The next BiBB summer school will be held early September 2026.

Beyond training, BiBB actively works on cultural change within the STEM community. Through national media, conference sessions and collaboration with scientific councils, the initiative challenges the idea that moving into policy represents a "loss" of scientific identity. Instead, it frames governance as a high-impact arena where STEM expertise is indispensable. In doing so, BiBB has established a nationally embedded pathway that did not exist before and has begun to shift how STEM researchers in the Netherlands perceive careers in public governance and policy. At the same time, BiBB emphasizes that embedding scientific thinking in public institutions is not about replacing political judgment with technical expertise. Rather, it ensures that when decisions are made in the face of uncertainty, the analytical mindset of scientists, such as attention to assumptions, limits, evidence, and complexity, is also present, thereby strengthening the decision-making process.

To summarize, by connecting STEM researchers to governance, BiBB strengthens public institutions while offering young researchers meaningful opportunities to make a societal impact. More broadly, initiatives like BiBB may serve as examples for STEM communities in other countries that wish to strengthen the presence of scientific expertise in public decision-making. ■

Patrick Decowski, Arlette Werner and Liedewij Laan

▼ BiBB Summer School participants during (left) a simulation of negotiations on a new EU budget, and (right) during a lecture by former chair of the Dutch senate, Jan Antonie Bruin, August 2025.

Teaching quantum entanglement with card games

– DOI: https://doi.org/10.1051/epn/2026205

Simple interactive activities help non-expert audiences to grasp the core concepts of quantum entanglement and the Nobel Prize-winning experiments that proved how quantum mechanics defies classical physics.

Even compared with other fields of cutting-edge research, the underlying principles of quantum mechanics are often deeply complex, and can contradict our everyday intuitions about reality. When communicating these ideas beyond the scientific community, this makes it incredibly challenging for researchers to simplify concepts enough to make them approachable, without sacrificing accuracy.

Through new research published in EPJ Quantum Technology, Valentina De Renzi at the University of Modena and Reggio Emilia, Matteo Paris at the University of Milan, and Maria Bondani at Italy's Institute for Photonics and Nanotechnologies present a new approach for introducing the concepts of quantum entanglement, and its experimental proof through the violation of Bell's Inequality – whose experimental demonstration earned the 2022 Nobel Prize in Physics.

Based on encouraging feedback from participants, the team are hopeful that their approach could be easily integrated into school curricula, and could also be applied with other non-expert audiences: including policymakers, industrial stakeholders, and the general public.

As part of the Italian Quantum Weeks project in 2024, De Renzi, Paris, and Bondani presented their approach through an exhibition named Dire l'indicibile, meaning "Speaking the unspeakable". Its interactive activities included a card game and a simplified staging experiment, which allowed participants to explore fundamental differences between the classical and quantum worlds.

The card game involves ordinary playing cards with coloured backs (blue or red) and ordinary fronts (black or red suits). Firstly, a dealer creates two decks in a specially prepared order, and gives one to each player. In this way, each card is paired with that in the same position in the other player's deck. Each player then measures both colours on every card, assigning numerical values (+1 for red, -1 for blue or black) – making sure to keep their deck in its original order.

By combining these values according to a specific formula, each pair produces a score of either +2 or -2. When averaged across all pairs, the final result must fall between -2 and +2 – a mathematical limit that applies to all classical systems where both properties can be measured simultaneously.

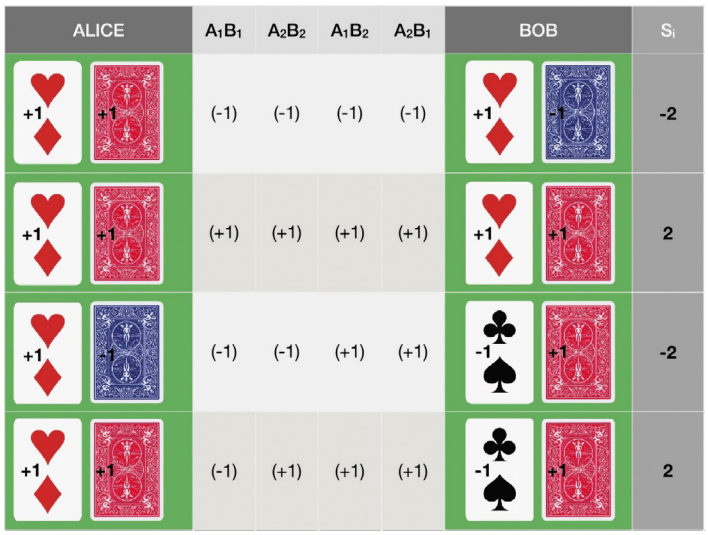
In contrast, the staging experiment recreates the key steps used to detect quantum violations of this limit. Again, a dealer prepares paired cards, but this time each card is sealed in a box, allowing only one colour to be measured. Players flip coins to randomly decide which property to observe, mimicking the constraint in quantum experiments where measuring one property makes the other undefined. After collecting these partial measurements, the dealer calculates the average correlation in the same way as before.

In this classical staging, the result still obeys the -2 to +2 limit – but in genuine quantum entanglement experiments, this bound can be violated, reaching values up to approximately + or -2.83. This violation proves that quantum correlations cannot be explained by any classical theory, no matter how cleverly constructed – revealing something fundamentally different about how nature operates at the quantum level.

By demonstrating both the experimental procedure and why classical systems are bounded, De Renzi's approach effectively communicates just how profoundly the quantum world differs from our everyday experience. The team hopes this method could lead to new breakthroughs in making quantum mechanics accessible to a diverse range of audiences. ■

Reference

[1] V. De Renzi, M.G.A. Paris & M. Bondani, *EPJ Quantum Technol.* **12**, 122 (2025). https://doi.org/10.1140/epjqt/s40507-025-00415-5



Understanding violation to Bell's Inequality with a card game.

How to design the perfect lecture

– DOI: https://doi.org/10.1051/2026206

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Given that lectures remain the mainstay of undergraduate physics provision, we argue that their design should be informed by the most up-to-date knowledge about teaching and learning.

Here (Wood 2026) we review key findings from the field of physics education research regarding the effectiveness of approaches to teaching lectures. Although students often report negative experiences of lectures we suggest that a well thought out lecture design can transform them into a valued collective learning experience which creates a sense of belonging and connection and leads to deep learning. Three areas worth paying particular attention to are:

1) Interactions between the lecturer and the students, 2) Interactions between students in small groups and 3) Students' experience of the lecture.

One of the key findings from the field of physics education research in recent years has been the demonstration of the efficacy of a teaching approach called 'active learning'. Compared to traditional lecturing, active learning leads to higher engagement, increased learning gains and greater student retention. Active learning includes a wide range of techniques but central to them all is that students have opportunities to engage in problem solving and to interact both with each other and with the teacher. For example, Peer Instruction involves asking students questions designed to make them think, rather than testing factual recall, alongside the opportunity to discuss the question in small groups. Discussing questions with peers has been shown to help students develop conceptual understanding and encourages them to explain their own thinking. Our research also shows that group discussions activate students to think differently about the problem, either by triggering them to use knowledge that they didn't realise they already have, or to try different types of problem-solving approaches, such as drawing a diagram, rather than plugging numbers into an equation.

It is equally as important to consider how lecture-student interactions can be used to enhance learning. Research indicates, for example, that when solving a problem on the board, asking students to contribute ideas about the next step encourages them to learn about the process of problem solving and teaches them to think like an expert. Lecturers can also create an environment where discussion and questions, particularly those which go further than asking for clarification or basic information, are encouraged.

Finally, there is evidence that how students experience a lecture affects how they engage with it. For example, our research shows that students often struggle with cognitive overload when there is too much new information presented in the class. When this happens they concentrate on making notes, and not on understanding the material. One way round this is to reduce the volume of course content, or to present some of it prior to the lecture (such as in a flipped classroom approach). We also found that students who are able to take time to think about a problem when solving it, rather than reaching for their first, intuitive response do better on standard tests of conceptual understanding of Newtonian mechanics. Finding ways to encourage slower thinking is therefore likely to be beneficial.

While lectures will remain with us in the short-term, the longer term outlook is less certain. We know that attendance has dropped and that (probably unrelatedly) students are increasingly using AI. Research is needed to understand how this is affecting their ability to learn physics. While it could be beneficial for ChatGPT to provide students with alternative explanations for difficult concepts, the effect of replacing lectures with AI entirely is an open empirical question which requires further research. ■

A. K. Wood, "How to design the perfect lecture", *Europhysics Letters* **153**, 10001 (2026)

Young (minds) at Heart

– DOI: https://doi.org/10.1051/epn/2026207

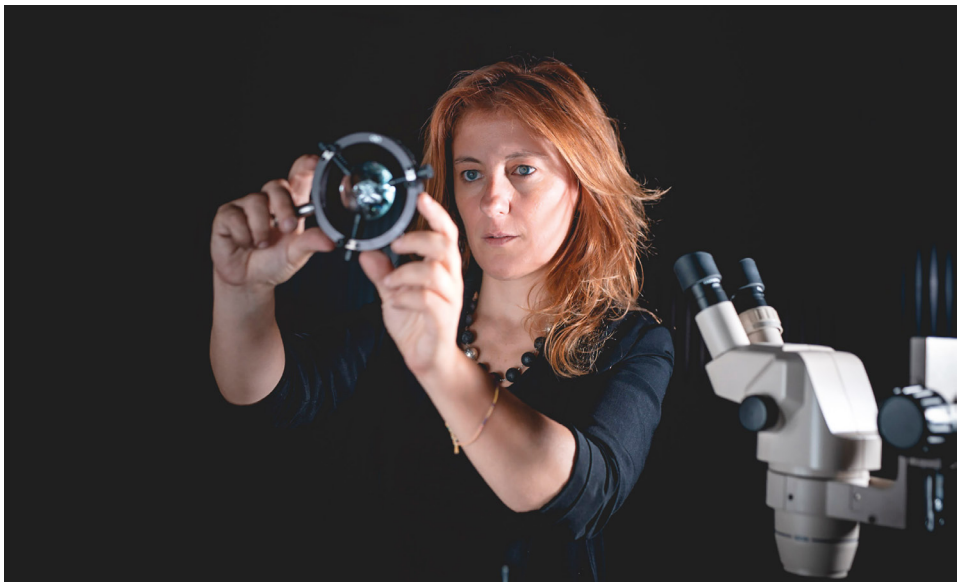
The EPS Young Minds programme has at its heart an action committee composed of and chaired by early career researchers. Members are recruited from the Young Minds sections and the committee, and its chair represent the programme, guide the distribution of funds and provide a link between the sections and the EPS. Participation in this committee might seem like a daunting prospect, and something which is difficult to combine with studying physics, nevertheless participating in Young Minds has been crucial to the career development of many of its former members. Here three former chairs reflect on their experience.

Antigone Marino

In 2010, I had the unique opportunity to be one of three physicists who, together with the European Physical Society (EPS), founded what would become the EPS Young Minds (YM) project. At the time, we shared a simple but ambitious vision: to create a European framework that would give young physicists a voice, foster connections across borders, and support professional growth beyond the traditional academic path. What I did not fully realize back then was how profoundly this experience would shape me, both professionally and personally.

From 2013 to 2016 I was Chair of EPS Young Minds. The experience was taking another turn, it was no longer just about having ideas but stepping beyond the boundaries of scientific research into leadership, coordination, and long-term strategic thinking. My role came with significant responsibilities. I was involved in coordinating national Young Minds sections across Europe, acting as an interface between early-career physicists and the EPS leadership, and contributing to the strategic direction of the initiative. This meant organizing meetings, moderating discussions among people with diverse backgrounds and expectations, and helping translate ideas into concrete actions at a European level. And most of all, finding the funding to grow the project.

In Europe, there were already several initiatives by young physicists, both internationally and nationally, but what made YM special was establishing it within the EPS, a federation of national societies. We had to speak different languages: not just spoken languages, but also the different languages that each society had at the national level regarding youth policies. This wasn't always easy, but it was a challenge that allowed me to understand European physics like I'd never seen it before. And I still believe this was one of the most important legacies YM and EPS have left me. In this multicultural environment, I learned how to negotiate, how to listen, and how to build consensus.



▾ Antigone Marino

EPS Young Minds connected me with motivated young researchers, senior scientists, policymakers, and professionals working at the interface of science, education, and society. These connections opened doors to new collaborations and opportunities, and they broadened my perspective on what a career in physics, and beyond, could look like.

To young physicists who are considering getting involved in EPS and Young Minds, my advice is simple: do it. Take part in the project, even if it feels demanding or unfamiliar. These experiences will enlarge your opportunities, expand your horizons, and equip you with skills that will stay with you far beyond any single role or position. Sometimes, the most important steps in a career are not the obvious ones, but the ones that challenge you to grow.

Finally, let me say that seeing YM continue to grow makes me think that EPS, and I in my own small way, have done well. Leaving a project is always a sad moment, letting go is hard. But

seeing that there are people who continue to nurture your dream is one of the greatest satisfactions of any career.

Roberta Caruso

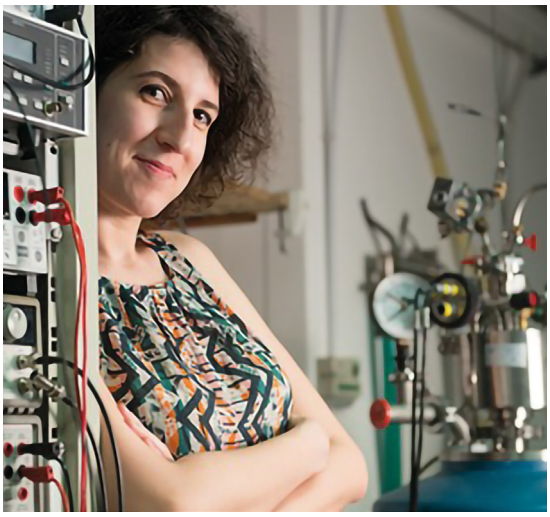
I have been part of EPS Young Minds since its inception in 2010. Around 2015, former YM Chair Dr. Antigone Marino—recognizing my drive as a young scientist—invited me to join the Action Committee. I was later elected Chair (2018–2020). My term ended just as the pandemic began, but I witnessed firsthand the network's tenacity in adapting to new challenges to support its members.

Joining the Action Committee was a turning point I didn't see coming. It gave me motivation and drive at times when my academic career felt uncertain. On several occasions, I questioned my professional value, and it was this project that kept me grounded. Through my involvement, I also learned more about myself as a scientist. While I enjoy tinkering in the lab, I realized I am not the person who "builds" science from scratch with sudden, brilliant intuitions. Instead, I'd rather discuss the massive, "big picture" implications of science with a room full of people. Young Minds was the ideal environment for valuing this way of thinking.

Looking back now, I find that colleagues frequently remember me for my leadership in YM as much as—or more than—for my scientific papers. At the time, I wasn't sure if that was a good thing, but I see now that YM gave me a "label." It distinguished me from the mass of researchers. It proved I wasn't just another physicist in a lab coat; I could be seen as a leader capable of building international communities.

Academia is tough, and there is no "easy mode" for success. But if you are willing to put in the work, Young Minds can genuinely help kickstart your career beyond the numbers that usually define academic progression.

One final thought: Don't settle. If your current research environment doesn't appreciate or support the service work you do for the scientific community through EPS, that is their loss. If they don't see how this makes you a better, more connected scientist, maybe it is time to consider moving somewhere that does. You might not realize it now, but you really are building a global profile for yourself, even though maybe this isn't the conventional way to do it. Don't let a local mindset hold you back: if you think there's value in building communities and networks, EPS Young Minds might be the right place for you.



▲ Roberta Caruso

Richard Zeltner

When I first joined the EPS Young Minds Action Committee (EPS YM AC) in 2018, I was excited to contribute to the development of a programme which has a scope and vision that aligns very much with my own beliefs. I found it to be a valuable opportunity to gain insights into the operations and the management of a large scientific organization, as well as to increase my professional network and gather experience in international scientific collaboration.

Looking back at my time in the EPS YM AC, and as committee chair from 2020 to 2022 now, it is safe to say that my expectations on the professional learning and growth opportunities have been met. Many of the activities I was involved in sharpened and extended my skillset, benefiting my overall professional advancement. A few examples that come to mind are contributing to the organization of large scientific conferences as well as student-led and aimed workshops, initiating collaboration with other scientific organizations and reviewing grant applications.

However, the very first associations that come to my mind when remembering my experiences in EPS YM are actually about the people I have met and connected to. Personally, I completed all my studies in Germany, and never quite ventured out far enough to experience life abroad or academic systems in other parts of Europe and beyond. But the conversations I had about living abroad, cultural diversity, different academic systems and struggles of the young minds I met, presented an incredibly enriching experience that helped me to vastly widen my perspective. This brought me a little bit closer to the 33 countries that are part of the EPS Young Minds network.

I believe that most interpersonal skills cannot be learnt in the classroom or books. I have, however, found them to be highly valuable for my personal and professional growth. Connecting with people from different backgrounds and learning how to connect and relate to them, is a critical skill in today's fast-paced and diverse work environments. My time in EPS YM AC taught me many lessons on how to do so effectively.■

▼ Christophe Rossel and Richard Zeltner

What's in a physics degree? High quality education in the age of AI

by David Sands,
Independent Physics Educationalist based in East Yorkshire, UK
DOI: https://doi.org/10.1051/epn/2026208

It is fair to say that the world is currently in turmoil. Aside from the continuing war in Ukraine, with all the uncertainty this brings for the future of peace in Europe, the recent outbreak of war in the Middle East has sent shock waves around the world and threatened the global economy. At the time of writing, the war is still being fought and we have no idea of the long term consequences. However, there are other forces at work which threaten even greater disruption to the established order. Generative AI is being talked about in the same terms as the first industrial revolution, which saw mass migration from the country to the towns and the development of a very different way of life. The way of life in the age of AI is thought by many to be one of mass unemployment.

It seems unlikely at present that AI will replace the physicist. Despite the name, AI is not really intelligent in as much as it doesn't appear to be able to synthesize new information. What it can do very effectively, and far better than humans, is summarize a wealth of existing information, but even here it suffers a difficulty. There have been some notable incidents in the UK in which AI appears to have been used to summarize legal arguments only for it to turn out that AI has fabricated content. Most notably, the judgement in the Sandie Peggie case was changed twice when it turned out that quotations from previous cases cited in the judgement did not reflect the reality. Whether these are in-built deficiencies in AI that will always exist or whether future versions will be able to overcome them remains to be seen, but even with these limitations AI in its current state already poses a significant challenge for educators.

The impact of AI on education cuts across disciplines and levels, but physics education is our particular interest and it is within that context that we must look at the challenges, solutions and possible benefits. We have arrived at the situation now where AI can solve most of the conventional problems an undergraduate would typically be set. The purpose of setting such problems is not only to assess what students know and can do, but also to provide a vehicle for the development of understanding and skills. It is no longer safe to assume that if students are set work to complete in their own time that the work they submit will reflect any cognitive effort or input by the students. Sands and Henriegel discuss the challenges this poses for educators and the possible impact this will have on the design of degree programmes. Yeadon discusses the impact of AI on assessment at all levels and in particular at university, where educators have more freedom to design assessments that overcome the challenges posed by AI.

The fact that AI can solve most problems faced by undergraduates means that potentially it can be harnessed both to help with assessments and to provide tutorial support. The articles by Babayeva et al and Küchemann et al explore these aspects with examples from their own educational research into supporting students with AI.

As AI develops and educational systems adapt, there will no doubt be other challenges. All we can do at present is meet the challenges we face. They are considerable and I believe we are on the threshold of some of the most significant changes to the structure of education to occur in decades. These four articles give some idea of the possibilities. ■

GENERATIVE AI WILL CHANGE THE WAY PHYSICS IS TAUGHT AND ASSESSED

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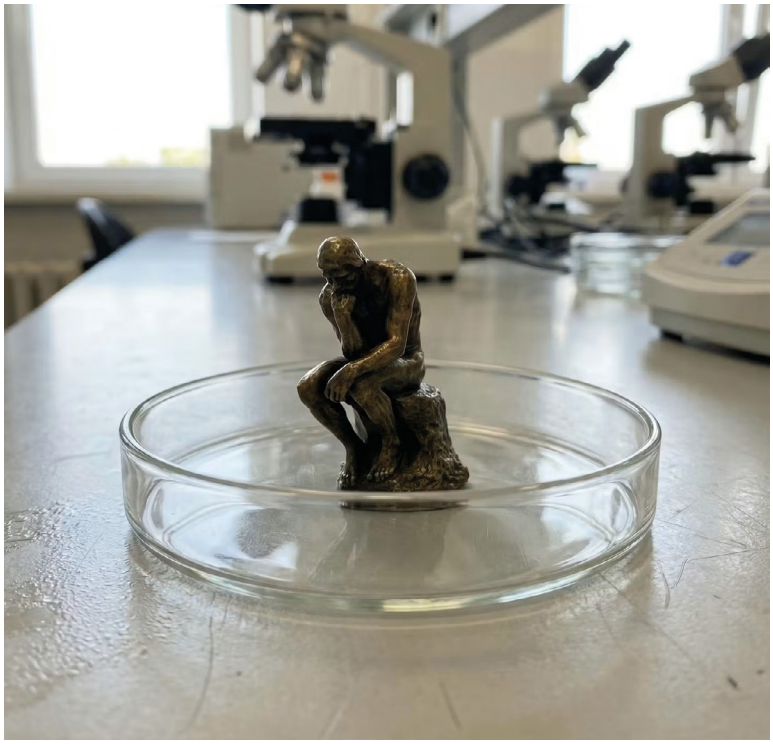
It is not too long ago since generative AI tools, such as ChatGTP, were being discussed within Arts and Humanities for their ability to generate good quality essays with seemingly no easy or reliable method of detecting their use, but quantitative subjects like physics seemed immune. AI tools did not seem to be very good at solving problems, and as problem solving in all its forms is a huge part of a sound physics education, generative AI did not seem to pose much of a threat. Those days are no more. Generative AI can now solve pretty much any problem we might set to an undergraduate and we face the same challenges that beset our colleagues in the Arts and Humanities.

Generative AI presents both challenges and opportunities. Most obviously, if students are set coursework, of whatever kind, with the intention that that marks awarded to the attempted solution should count towards a grade, educators need to be confident that students have genuinely done the work. This has led to calls in the UK for a return to timed, unseen examinations as the only way to be sure that students' knowledge and understanding is tested. This raises two immediate issues. First, although the timed examination has long been a feature of many physics degrees, they are not effective tests of conceptual understanding, they widen inequity, and it is by no means clear that they will remain appropriate assessment tools in an age of AI. Secondly, emphasizing the threat to the integrity of current assessment methods underplays the other, potentially very significant, changes that the emergence of generative AI will bring about. This article ...

▲ Who is doing the work? Maintaining the value of a degree in the age of AI.



▲ **FIG. 1:** Rodin's The Thinker sitting in a Petri dish. Scientific observations of thinking and reasoning have revealed complex mechanisms like mental modelling and dual processing theories that can inform approaches to education. Note: this picture was generated using AI.

• • • offers a personal view of the challenges to learning and assessment rising from the emergence of generative AI. We are not experts in AI, rather we have long been involved in accreditation of physics degrees in the UK and Ireland (see for example, Knowledge and skills changes to accreditation herald pedagogical transformation in the UK, David Sands, Europhysics News 50/5-6, 2019, p. 38-40) and are deeply concerned about the potential impact of AI on educational standards.

The introduction of any new technology inevitably means that some skills are either no longer needed or not used to the same extent. Mental arithmetic has suffered from the ubiquity of electronic calculators. Young people rely on digital time pieces and struggle to read an analogical clock. Are these important? Probably not, but AI poses a different challenge. It is no longer necessary to possess a wide-ranging knowledge, nor is it necessary to know how to use that knowledge. AI threatens the very foundations of education. Unless we can define what students should know and be able to do in the age of AI, and therefore what they should be taught, how are we going to produce effective graduates? AI threatens not only the future of higher education but the future of physics as a discipline, not necessarily because it will be able to replace physicists, but because we might not be able to produce physics graduates with the necessary knowledge and skills. This is the real conundrum. AI is not foolproof. It is well known that it hallucinates, but in these early days there are people with sufficient knowledge to recognise when the conclusions or arguments AI generates are false. However, if AI is allowed to subvert the normal processes of thinking and reasoning, how will we produce people with such knowledge and expertise?

The conventional approach to thinking and reasoning, at least within the UK, is to see cognition as a heirarchy of ever more complex processes as set out in Bloom's taxonomy. However, modern theories of thinking and reasoning suggest a very different set of mechanisms. There isn't space in an article of this nature to describe these theories in detail, but they may be illustrated with an example of the kind of qualitative question often used to test conceptual understanding. It is a well-known question and you might be familiar with it. Suppose a small wooden rowing boat on a lake contains a very large stone. The occupant of the rowing boat lifts the stone and drops it overboard where it immediately sinks to the bottom of the lake. As measured against the side of the boat, does the level of water rise or sink? The answer might be obvious to you, but the process by which the answer is arrived at will not be at all obvious. Very likely, you were building up a mental image of the situation as you were reading the text. This ability to build iconic, pictorial representations of the world around us is known as mental modelling and there is substantial evidence that this, rather than logic, is the primary mechanism of human reasoning.

One of the features of mental models is that we can animate them. Mental models do not consist of a sequence of static mental images and as you constructed your mental model you might well have imagined the occupant of the boat lifting the stone and dropping it. You might also have imagined the stone sinking and the boat rising in the water. However, the last depends on whether you implicitly understand the connection between the load in the boat and its depth in the water. If you do not, you have no basis for imagining the boat rising as the stone is released overboard.

This kind of reasoning involves very few cognitive resources. The processes of constructing mental images and animating them are automatic and the conclusions arrived at by such processes would be considered intuitive. Nonetheless, they can be surprisingly accurate and the mental modelling account of reasoning explains very simply why even young children can reason effectively when, according to Piaget, the ability to reason logically does not develop until just before the teenage years and continues to develop through adolescence.

Intuitive reasoning is not always correct and not always possible. Had the question asked about the absolute level of water as measured against an external mark, an intuitively generated answer would be unlikely as there is no obvious relationship between the load in the boat and the total displacement of water. Then, logic would have to be used to build the mental model. Once constructed,

though, it is available for future use. Suppose that instead of a stone, the boat contains a large volume of something, say polystyrene, that has a significantly lower density than water. If posed entirely independently of the situation with the stone, it is possible that the preceding mental model would not be invoked and reason would be required to work out what would happen. However, if it were asked as an extension of the first question, it is possible that an intuitive line of reasoning along the lines of *greater density than water, the boat rises* ⇒ *lower density than water, the boat sinks*. Such a conclusion would, of course, be incorrect, but whether the reasoner would recognise this and rethink the answer depends on the reasoner's state of knowledge and understanding.

This process of generating an intuitive answer and then rethinking the problem logically in response to self-generated doubts is known as dual processing. Historically, dual processing theories and mental modelling have developed independently, but they appear to be connected. Mental models that are either cued or generated by automatic processes might lead to correct answers, but they might also be incorrect, but if the incorrect solution seems believable and there is insufficient reason to doubt it, the logical reasoning that will lead to the correct solution will not be initiated.

Mental models can be very specific, which can lead to the appearance of fragmented knowledge or inconsistent reasoning. The physics education research literature is full of examples of students who can apply a law or principle in one context but not another, although we are not aware of examples involving Archimedes' principle. So what does this all mean for physics education in the age of AI?

As ever, students need to be able to think and reason. This is especially so with AI that does not produce totally reliable outcomes. Students using AI will need to be able to appraise the outcomes critically. They will need practice in building and using mental models of concepts in a range of contexts in order to build a coherent framework and to recognise when an argument might be false. The conventional approach of setting students problems to be solved in their own time will no longer suffice as it will not be clear that students have done the work. This will be a matter of the integrity of assessment if that is the purpose of the work, but it is also about ensuring that students do the things they need to do to develop their knowledge, skills and understanding. One way to ensure that students have actually built and used models would be to find room within the curriculum for extensive in-class problem solving, but educational research may well reveal other effective approaches, possibly involving different forms of assessment.

Generative AI is very likely to affect approaches to assessment. Assessment drives learning. If students face assessments that predominantly require recall with limited solving of a known type of numerical problem, students will put their effort into memorising information and familiarising themselves with examples of the kind of problem they are likely to face. If we want students to develop their abilities, possibly with the use AI, the assessment should focus on processes rather than outcomes. Then, there is simply no advantage to using AI to solve a problem in order to find the answer, but there is every benefit to using AI to understand the nature of a problem and its solution.

Currently, assessing processes is difficult. There are some examples of such assessments within the literature, but the practice is not widespread. Assessing thinking and reasoning, whether formatively for development or summatively for grading, is likely to involve some kind of interaction between the assessor and the student. In a conventional setting this would be expensive of staff time, but it is possible that robust AI systems can be developed that will undertake the task reliably. This is a fertile area for further research.

In summary, generative AI poses a significant challenge, but it also presents opportunities for educators. Other articles in this issue focus on some of the ways educators are using AI now to the benefit of students and staff and such is the pace of development that what AI cannot do now will very likely be possible very shortly. However AI is used, it is vital that the thinking and reasoning processes essential to effective learning are not by-passed and the physics degree of the not too-distant future is likely to look very different. If extensive supervision of in-class activities is needed, this could lead to further differentiation of teaching from research, which could pose a challenge for the discipline itself. One thing seems clear, though: AI is here to stay and students are already using it. How they use it and what benefit they derive from it will depend very much on what is expected from them by way of assessment. The challenge facing educators to develop and adapt is thus very clear. ■

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WHEN AI GETS AN A: INTRODUCTORY PHYSICS EDUCATION WHEN ANSWERS ARE CHEAP

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Artificial intelligence is entering physics classrooms as a practical tool that can solve physics problems at the level of high-performing students. We argue that to remain relevant, physics education must refocus on scientific practices. Here we share experiences from two complementary settings: laboratory work and written assessment, and conclude with practical recommendations for educators.

Over just a few years, AI systems have progressed from struggling with introductory physics problems [1] to performing at the level of top-scoring students [2]. With today's multimodal "reasoning" models (*e.g.*, GPT-5, Gemini-3), a student can photograph a typical problem, ask for a solution, and often receive a polished, correct answer within seconds. If physics education is reduced to producing the right answer, many students who take physics as a service course may reasonably ask: why bother?

Yet expert physicists know that just the correct answer is rarely the point. "Thinking like a physicist" involves a complex epistemology: how we decide what to trust, how we justify claims, and how we connect models to evidence [3–5]. These are universal competencies that transfer well beyond an introductory "service" course and are worth learning (and persevering) even when answers are readily available. Traditionally, physicists do this through derivations from first principles and through laboratory work.

That is where physics education now needs to move: toward assessing and supporting *ways-of-knowing* rather than answer production — ideally with personalized human guidance, but at scale often with AI assistance. AI can serve in dual roles here: both as a partner that prompts reasoning and as a tool that helps instructors provide feedback at scale. Even though this comes with the risk, as skeptics might put it, of putting the fox in charge of the henhouse. In this work, we offer two perspectives: how an interactive GPT-based assistant can support laboratory learning, and how multimodal AI tools can extend this assistance to homework and exams through structured grading workflows that retain human oversight.

AI as a Virtual Assistant in Physics Laboratories

Imagine a crowded physics lab: thirty students, one teaching assistant, and a lot of waiting. When students get stuck on a question or a calculation, they often lose valuable time or, most importantly, focus on the task before help arrives. To address this, we implemented an AI-based virtual lab assistant designed to provide immediate, low-stakes formative feedback during laboratory activities. The goal of this project was to understand how students use such an assistant and to evaluate whether an AI system can offer meaningful educational support without undermining established pedagogical goals.

Developed at Portland State University, the custom web-based platform integrated a GPT-based chatbot directly into an introductory physics laboratory course (figure 1). The assistant was available first to students working in person and later to online students using experimental tools at home, who typically have even less contact with a teaching assistant. In both contexts, the AI was designed to respond to individual student queries in

real time, offering guidance while avoiding direct solution disclosure. This setup allowed the assistant to act as an always-available first point of support, particularly valuable in remote lab settings where synchronous TA interaction is limited.

Throughout the deployment, the AI assistant demonstrated clear strengths and persistent limitations. The assistant answered more than 85% of student queries correctly and beneficially for students' understanding of the task [6]. It handled theoretical and conceptual questions well, often requiring only minimal contextual information, and provided clear explanations that helped students interpret questions or verify answers. Experimental, numerical, and measurement-based questions, however, were more sensitive to prompt phrasing and context, occasionally resulting in vague, inconsistent, or incorrect responses. Over time, the integration of a feature that could automatically run code and perform calculations significantly improved the system's handling of formula-based and numerical tasks, reducing, but not fully eliminating, errors in calculation and value interpretation.

Student feedback reflected a generally positive but cautious reception. More than 60% of students who used the assistant in their at-home practice agreed that it helped them better understand the lab material. Many students found the assistant particularly useful for checking answers, clarifying concepts, and gaining confidence before submitting work. For instance, one of the students noted that *"Whenever I got stuck, it would help point me in the right direction"*.

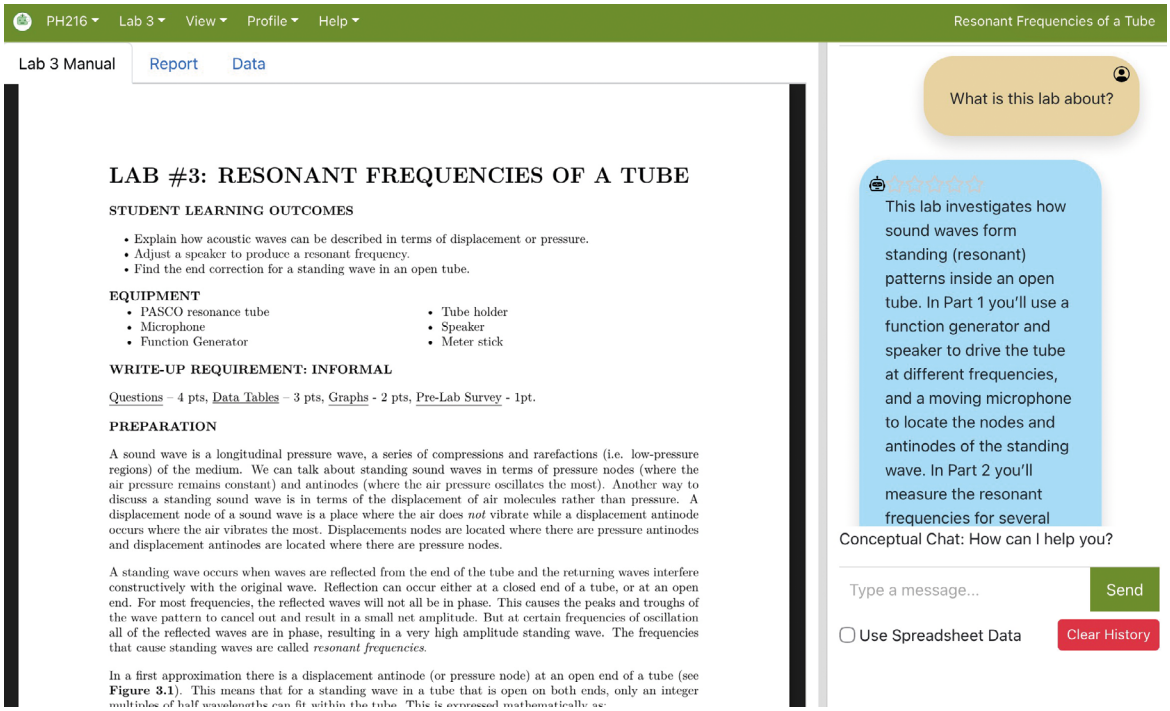
At the same time, students expressed frustration when the AI produced repetitive explanations, overly verbose responses, or numerical errors.

For example, one student mentioned, *"Sometimes it gives overly complicated responses to something simple"*. In several cases, students reported reduced trust after receiving incorrect guidance. During the in-person labs, students who were accustomed to TA interaction continued to prefer human support, while remote students more strongly valued AI's constant availability.

Overall, our experience suggests that an AI-based lab assistant can meaningfully enhance laboratory learning as a complement, rather than a replacement, for human instruction. The assistant proved particularly effective as the first line of support for low-stakes formative assessment, reducing wait times and reinforcing conceptual reasoning for both in-person and at-home students. Recent advances have resolved many early limitations, and the AI assistant now produces detailed explanations, sometimes even more extensive feedback than human teaching assistants due to greater time availability. They do, however, make occasional, unexpected errors. LLM-based tools remain probabilistic systems, underscoring both the significant opportunities and the pedagogical risks of integrating AI into physics laboratory education.

AI as a Virtual Assistant for Physics-Problem Solution Feedback and Grading

Even in a digitally saturated classroom, a large fraction of what we value in introductory physics problem solving is still most naturally expressed as handwritten work. Derivations are not just sequences of equations; they are visual objects that encode structure and intent. Mathematical typesetting is cumbersome under time pressure, and many of the marks that matter for reasoning—underbraces and term annotations, arrows ● ● ●



◂ **FIG 1:** Student view of the AI-based lab interface.

• • • indicating substitutions, side notes about limiting cases, quick sketches and free-body diagrams, small tables of units or sign conventions—are frictionless on paper but awkward to represent in plain text. In practice, the "image" of the derivation carries information that instructors use to diagnose understanding [7].

Historically, that same "image-first" reality has been a bottleneck for scalable feedback. In large courses, it is hard to provide rapid, individualized commentary on handwritten reasoning, so we often defaulted to answer checking, delayed feedback, or sparse rubric marks. Modern multimodal AI systems change this constraint: they can ingest a scan of a student's work and produce an interpretable response—imperfectly, but well enough to enable new workflows where the derivation (the way) stays central.

Below are two complementary cases: AI-supported homework feedback (formative) and AI-assisted exam grading (summative), both designed around the same principle: automate only what we can justify, and keep humans accountable for validity and fairness.

Case 1: Homework feedback

The Ethel project describes a practical pathway for giving students feedback on handwritten homework in large-enrollment courses. Students submit scanned PDFs; the system converts the handwriting into a structured representation [8]. The key design choice is that the AI is not asked to "solve the problem from scratch" in a vacuum. Instead, the workflow injects the problem text and an instructor-provided sample solution so the feedback is anchored in the course's notation, definitions, and expected reasoning [8].

A second design lesson is tonal but important: early iterations prompted the system to address students directly and be "encouraging," but the prompts were revised toward more impersonal, task-focused feedback. The authors report that anthropomorphizing quickly wore off and sometimes led to patronizing phrasing or unsolicited study advice — an unhelpful distraction from the goal of clear, actionable commentary.

What did students think? In the reported deployment, students rated the feedback as helpful and correct in about three-quarters of cases. The dominant weakness was not conceptual physics reasoning but handwriting recognition: the system tended to *underestimate* correctness when the OCR/interpretation step misread what students wrote, and students rated recognition accuracy as only about half in those cases.

For our purposes, the takeaways are straightforward and actionable:

- Formative feedback on handwritten work is now feasible at scale, especially when the AI is anchored to course-specific reference materials and sample solutions rather than operating "free-form."
- The practical failure modes often sit "upstream" (recognition and parsing), so any deployment must be designed with transparency and graceful failure: uncertain cases should be flagged, not forced.

Case 2: Exam grading

The summative context is different: exams are high-stakes, and the tolerance for unfairness is low. We treat AI grading as a human-in-the-loop process where the central question is not "can AI grade?" but "when can we trust it, and when must a human intervene?" [9]

The study introduces a practical reliability dial: rubric-level grades are generated by the model, but acceptance is governed by threshold parameters in an independent test-theoretical analysis (a correctness threshold and an uncertainty threshold using Item Response Theory), so that only sufficiently reliable judgments are auto-accepted [9]: *accept only high-confidence "correct" judgments*, while routing "incorrect/uncertain" judgments to humans, albeit at the cost of increasing the instructor's involvement.

We find configurations around $R^2 \approx 0.91$ between TA- and AI-assigned scores when auto-grading roughly half of the grading decisions, and $R^2 \approx 0.96$ when auto-grading about one fifth — illustrating how instructors can choose their balance between workload reduction and conservatism.

There's no magic, though. Attempts to iteratively improve grading rules via detection of problem parts that seemed to have unusual scores (apparently too easy, too hard, *etc.*) produced only minimal gains. Human rubric construction, proofreading, and judgment remain essential—particularly because students can produce diverse solution paths, and handwritten work can include ambiguity that the model interprets inconsistently. In other words, psychometrics helps quantify grading validity and manage risk, but it does not eliminate the need for careful assessment design.

In the coming semester, we will use this approach operationally—not as full automation, but as conservative triage. The workflow is deliberately designed to keep learners and educators in control:

1. AI proposes grades only where it meets strict acceptance thresholds.
2. Students are empowered as the first line of accountability: they can veto the AI grading of any problem part they believe was misjudged.
3. Vetoed parts go to a teaching assistant for final adjudication; that judgment is final.

This "student veto" mechanism does two things simultaneously. It makes the system more legitimate (students are not trapped by machine judgment), and it bounds workload by escalating only contested parts. Our current calibration yields <2% false positives on accepted "correct" judgments, which is why we are confident we are

not "giving away the farm." At the same time, we will be explicit with students about an uncomfortable truth: TA review is the gold standard, but it is not infallible—there will be cases where a human second look disagrees with (and may even be harsher than) the AI's initial decision.

Implications and Recommendations

The integration of artificial intelligence into physics education is not a distant prospect - it is already reshaping classroom practices. Our experience with AI-based tools in the physics classroom demonstrates clear benefits: reduced waiting times for assistance, fast feedback, and opportunities for personalized learning. However, these advances do not eliminate the need for human oversight. Generative models remain prone to occasional inaccuracies and inconsistencies, particularly when interpreting experimental data or applying nuanced judgment. At the same time, these developments raise important questions about pedagogy, ethics, and the evolving role of educators.

Based on our experience:

- Effective AI integration favors seamless incorporation into existing workflows without mandating use.
- Human oversight remains essential, especially for summative assessment.
- Thoughtful task design and flexible answer expectations help avoid misleading feedback.
- Students should be supported in developing critical AI literacy.
- Ethical, transparent practices addressing privacy, bias, and equity are necessary to sustain trust.

Looking Ahead

AI will not replace educators, but it will redefine their role. Teachers will increasingly act as designers of learning environments where AI augments instruction rather than dictates it. The challenge, and opportunity, lies in using these tools to enhance engagement and conceptual understanding while safeguarding the integrity of physics education. ■

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THE GENERATIVE AI-INQUIRY CYCLE

Stefan Küchemann, Patrik Vogt, Yavuz Dinc, Christoph Hoyer and Jochen Kuhn

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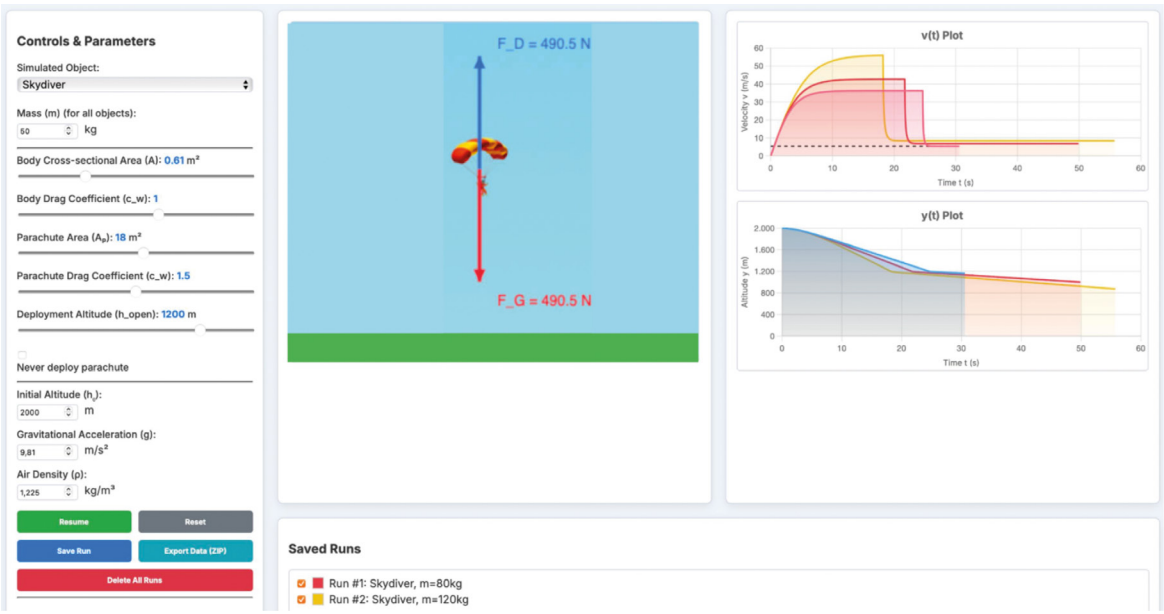
Generative AI offers various opportunities to improve physics education. However, there are also several non-obvious challenges when integrating generative AI into physics classes and lab courses, such as low cognitive activation, unreflected acceptance, and metacognitive laziness. In this overview, we present three examples for physics lab courses, in which generative AI integrated at different points into existing sequence of inquiry-based learning (Pedaste *et al.*, 2012).

Pedaste and collegues (2012) describe the classical inquiry-based learning cycle as consisting of five steps: (1) Orientation, in which learners are introduced to the topic and the learning challenge, (2) Conceptualization, in which learners develop the research questions and hypotheses, (3) Investigation, in which learners experiment, collect data, observe a phenomenon, analyse and interpret the experimental data, (4) Conclusion, in which learners identify relationships in data, refine theoretical assumptions and draw conclusions, and (5) Discussion, in which learners share and discuss the outcomes, reason, and reflect on their findings. The examples we present show how different aspects of this cycle can be enhanced by the use of generative AI.

The first example redefines the classical inquiry steps (1) and (2) by allowing teachers and students to create customized physics simulations using generative AI from scratch. The second example uses smartphone sensors and enhances step (3) of the inquiry cycle using generative AI to introduce students to more advanced data analysis techniques. The third example supports the steps (4) and (5). This example uses a pre-prompted generative AI agent to stimulate students' interpretation of findings and experimental observations by asking questions to students and providing feedback to their answer.

Note that in each case, it is essential that students are not overwhelmed by the use of GAI or that students do not offload learning-relevant tasks to the GAI. To prevent this, Kuhn *et al.* (2026) suggested the AIRIS framework (Activate-Inquire-Reflect-with Intelligent Support) which ensures students' engagement and preserves epistemic practices in physics experimentation.



▸ **FIG. 1:** Interface of a simulation to inquire concepts related to friction developed using generative AI.

Example (Orientation & Conceptualization): Physics Simulation using generative AI

In our prototypical example, this design phase is implemented as a browser-based simulation of free fall with quadratic air resistance in 1D, described by:

$$m \cdot dv/dt = m \cdot g - \frac{1}{2}\rho A C_w v^2$$

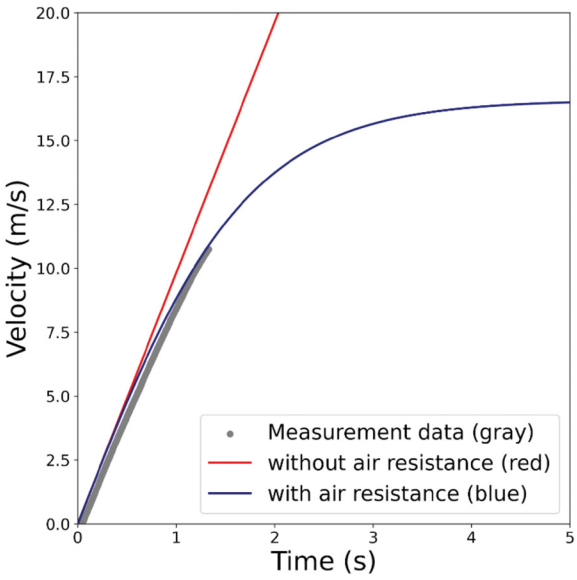
A single, detailed prompt specifies (i) the physical model, (ii) the interaction design, and (iii) the visual layout. To align the simulation with hypothesis-driven exploration, the prompt requests adjustable parameters (*e.g.*, m, ρ, A or drag coefficient C_W), physically meaningful defaults, and transparent SI units throughout. It also allows an optional parachute stage to support hypotheses about transitions between two terminal velocities.

Crucially, the prompt defines the user interface and didactic affordances, including a control panel with sliders and input fields, a canvas animation showing the falling object with force arrows for weight F_G and drag F_D (with arrow lengths scaled to computed forces), and live plots of v(t) and y(t) with labelled axes, units, and a clean, user-friendly design [6]. The result is a single self-contained HTML file that runs locally in any browser without installation, enabling rapid deployment in class, while allowing experimental runs to be downloaded locally as CSV files for further analysis (see Fig. 1).

In Orientation, the teacher frames the topic and the learning challenge using the phenomenon and the interactive representation. In Conceptualization, students develop research questions and hypotheses and translate them into testable simulation specifications. They decide which variables to vary, what to hold constant, and which observable outputs (force arrows, v(t), y(t)) should confirm or contradict their expectations. This makes modelling assumptions explicit and turns hypotheses into actionable specifications before any data collection begins.

Example (Deeper Investigation): Smartphone experiments with generative AI

Smartphones have evolved into mobile mini labs: with built-in sensors such as accelerometers, microphones, GPS, or LiDAR, they can capture a wide range of physical data (Kuhn & Vogt, 2022). Their widespread availability, intuitive usability, and the ability to conduct experiments spontaneously make them suitable measurement tools in school contexts. Studies indicate that their classroom use increases motivation and strengthens both physics self-concept and conceptual understanding (*e.g.*, Becker *et al.*, 2020). Combining smartphone experiments with AI-based analysis leads to the concept of AI-Supported Mini-Labs and allows a deeper analysis of the measurement data (Kuhn *et al.*, 2026).



◂ FIG. 2: Comparison of analyzed measurement data with theoretically modeled curves.

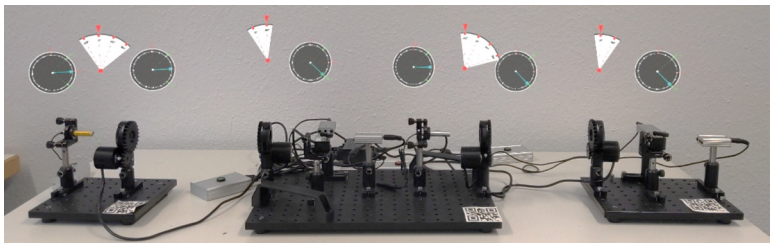
Multimodal AI systems add new possibilities for data analysis. They perform routines such as smoothing, numerical integration, regression, or statistical evaluation—tasks that often exceed students' mathematical skills. An experiment on free fall with air resistance illustrates this approach. Students analyze their own measurement data and directly compare them with theoretical predictions. No additional modeling software is required. Using a multimodal AI system (here Gemini 3 Thinking), data analysis, modeling, and comparison can be conducted within a single tool. This simplifies the entire process—from experiment to evaluation to model construction—and makes it more accessible. The downloadable prompts in the issue's download section accompany the article and provide a description of the experiment as well as the generated results (see Fig. 2).

The dataset can only be described satisfactorily when air resistance is included. Students would typically be unable to perform the necessary numerical integration or solve differential equations independently.

In sum, combining smartphones as experimental tools with generative AI as a multimodal assistance system offers a promising pathway for individualized physics learning and more advanced analyses at university level (Kuhn *et al.*, 2026). However, empirical evidence for positive learning effects is still required. Students must also learn to use these tools critically and reflectively, developing AI-related interdisciplinary communication competence.

Example (Conclusion and discussion): Reflection and Feedback during experimentation

In quantum physics, learners frequently encounter profound conceptual difficulties including making sense of counterintuitive quantum concepts. Through the combined use of holograms to visualize ● ● ●



▲ FIG. 3: Screenshot of the learning application showing the components of the basic experimental setup (cf. Thorlabs, n.d.) arranged on the table. In the enhanced version presented here, additional virtual overlays visualize otherwise inaccessible photon states and experimental parameters.

• • • otherwise inaccessible aspects of quantum physics and generative AI, instructional support can be effectively realized in such a complex inquiry-based learning environments, as illustrated in the following example:

Figure 3 illustrates an experimental setup through which the BB84 protocol for quantum cryptography can be understood by means of an analogy experiment. The experiment involves three parties: Alice, who encodes key bits (0 and 1) in different bases (+ and ×); Bob, who receives and measures the bits sent by Alice; and Eve, who attempts to intercept the key bits in such a way that her presence remains undetected by Alice and Bob.

The redesign of the commercially available kit described here enhances conceptual accessibility by extending the original setup in two key ways [7]. First, complex quantum-mechanical states are visualized through holographic projections that are directly integrated into the experimental setup and viewed through specialized glasses. Second, the system enables interactive verbal engagement with a generative AI. Through this combination, students receive individualized feedback that supports them during discussion and conclusion in refining their understanding of the underlying processes and the quantum-mechanical concepts involved.

An initial study (for detailed results see Coban et al, 2025) showed significant improvements in students' performance after feedback from generative AI compared to a condition without generative AI. Furthermore, an analysis of eye-tracking data collected during interactions with the AI revealed that the generated feedback systematically directed learners' visual attention toward the relevant components of the experimental setup.

Summary

In these three examples, we have shown that in comparison to classical inquiry, the integration of generative AI into inquiry-based learning offers a personalized pathway for orientation and conceptualization, a deeper analysis of measurement data, and enhanced engagement and discussion. With careful design, integration of generative AI creates a meaningful augmentation of epistemic practices and stimulates a deeper engagement with the content, thereby improving the quality of education. ■

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WHEN THE ANSWER IS FREE

Will Yeadon – Durham University, UK – DOI: https://doi.org/10.1051/epn/2026212

Generative AI can now solve the vast majority of physics problems a typical student will encounter until the end of a master's course. As the cost of producing correct answers approaches zero, physics education must pivot from valuing the "product" to valuing the "process." This shift requires a reimagining of how we teach, assess, and verify understanding.

The End of the Struggle

Current large language models perform extremely well on structured physics questions, including short calculations, standard derivations, and brief written explanations. Earlier versions often made arithmetic mistakes, but these errors are becoming less common as models gain access to integrated calculators and symbolic tools. Figure 1 illustrates this rapid advancement. Reevaluating earlier work on how ChatGPT-3.5 answered physics questions [1] shows 81% at GCSE (for age 16 in the UK), 63% at A-Level (for age 18 in the UK), and 23% on university textbook questions. By contrast, ChatGPT-5.2 reached 99% for GCSE, 96% for A-Level, and 94% for university questions. While invigilated pen-and-paper exams remain immune to AI, they are only one part of a broader assessment landscape.

If a student pastes a homework question into a chatbot, they receive a fluent and usually correct answer. The correct formula appears, the numerical result is calculated, and the explanation is structured. In this scenario, the struggle is removed. However, a struggle in learning physics is not an inefficiency, but arises from the cognitive effort required for learning. It is the moment when a student realizes they do not know which equation applies, or when algebra fails and must be retraced.

When answers are free, that friction is reduced. While AI could theoretically strengthen learning by functioning as an adaptive tutor, the reality is that when students are tasked solely with getting the answer correct, they will use AI as a shortcut. It is therefore unsafe to design assessments on the assumption that AI cannot perform a given calculation. The more stable approach is to assume that while AI can do a task, producing an answer is not the same as understanding it.

Reimagining Assessment at Secondary Education

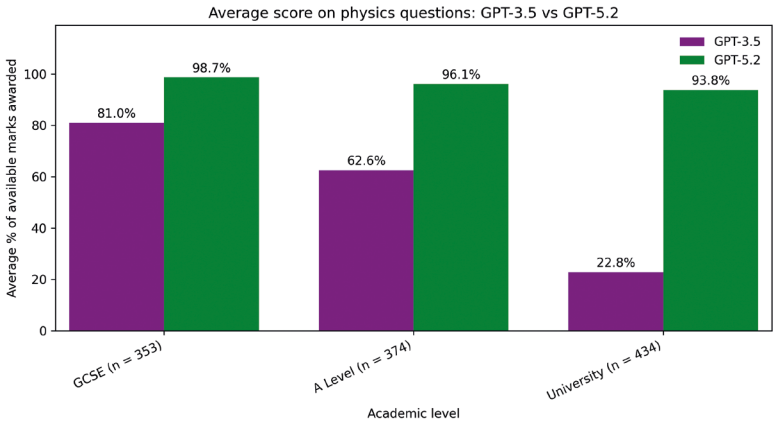
Secondary education has limited flexibility to respond because national curricula and examination boards change slowly. Schools cannot easily replace written homework with oral examinations due to constraints on staff time. However, homework can be redesigned to focus on the "why" rather than the "what."

For GCSE students, tasks can shift toward explaining puzzling phenomena. Puzzles naturally resist over-reliance on AI by making student thinking visible. Instead of a standard numerical answer, students might be asked to record a short reflection on how they arrived at their ideas or what they found confusing about a specific concept. These critical thinking-based tasks not only enhance physics understanding but equip students for the wider world.

A-Level has much the same constraints as earlier schooling. Examinations are high stakes with increased conceptual depth. If homework tasks at this stage can be fully automated, the signal about student understanding weakens. A more sustainable approach combines structured practice with in-class verification. Students could be asked to submit work developed with AI assistance but then be required to "teach back" or explain key steps under light supervision to prove understanding.

Reimagining Assessment at University

At the university level, assessment is more varied, providing flexibility to move away from take-home tasks like problem sheets and scientific coding challenges, which AI can generate in seconds. Not all forms of assessment are equally vulnerable. Examples include laboratory work where students must interpret real-world data; oral examinations where students must defend their ● ● ●



▼ **FIG. 1:** Comparison of GPT-3.5 and GPT-5.2 performance across academic levels. The rapid closing of the gap at the University level highlights the increasing vulnerability of traditional problem sets.

▲ **FIG. 2:** The "Human-in-the-loop" assessment model. A student "Interface" mediates between an AI "Oracle" and a student "Hand," ensuring cognitive engagement through mandatory interpretation.

reasoning in real time; and whiteboard reasoning, which forces the translation of thought into a visible, interactive process. However, all of these methods require significant staff time.

One approach worth considering is to use longer project-based work where assessments are given earlier in modules with class time dedicated to iterative development. This better matches professional research and the wider world of employment. While this doesn't prevent AI use, marking schemes can be designed to assess student learning and their engagement with specific class material or unique datasets that AI has not seen.

Another idea to embrace AI is the "human-in-the-loop" structure, such as pair programming with an AI oracle. In this model, one student has access to an AI "oracle" and acts as an "interface," while the other does not but acts as the "hand" to complete an assessment. Information must pass through human explanation and interpretation before it becomes part of the submission. For this to work practically, there must be physical isolation between the "hand" and the "oracle" so that the "interface" is required. This style of assessment accounts for the collaborative nature of modern work while ensuring individual students remain cognitively engaged.

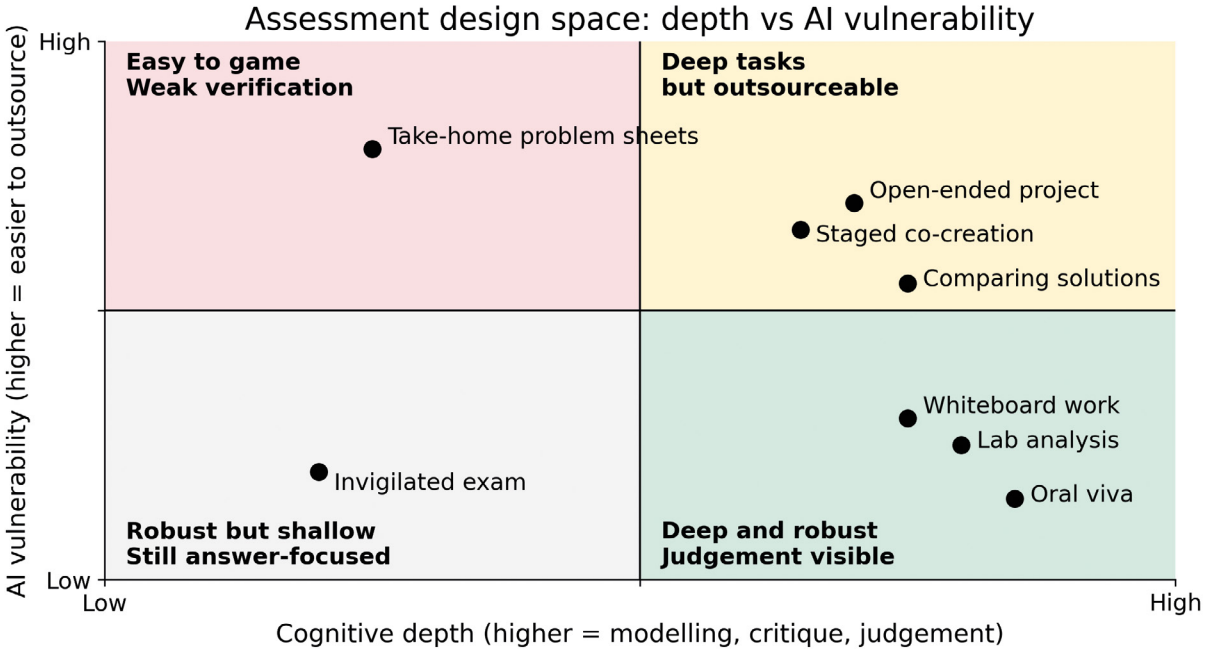
Verification in an AI-Saturated World

If AI can generate solutions on demand, the problem for educators is not generation but verification: how do we know that a student understands the work they submit? Historically, verification was indirect, a student who repeatedly produced correct homework solutions was assumed to understand the material. That assumption no longer holds. As correct output decouples from cognitive effort, the signal provided by homework has become noisy. When a measurement becomes a target, it ceases to be a good measurement, a phenomenon known as Goodhart's Law. This forces educators to articulate more clearly what they value.

Even without generative AI, assessment can be reimagined to include different forms of verification. Short oral follow-ups constitute one example: after submitting a problem sheet, a student might be asked to explain one solution in two or three minutes. Not to repeat memorized text, but to respond to a new variation of the question. Even light-touch questioning can help students internalize their reasoning.

Another approach uses comparative reasoning. Instead of asking for a single answer, students can be given two competing model outputs and asked to evaluate which is more physically plausible and why. This shifts the emphasis from production to judgment. The ability to critique a solution is cognitively different from the ability to copy one. There is also value in staged co-creation with AI, a student might first submit a prediction without AI, then refine it using AI, and finally reflect on

▶ **FIG. 3:** The assessment design space. Effective modern assessment should move toward the lower-right quadrant, prioritizing deep cognitive tasks with robust human verification.



the differences. This makes the interaction with AI explicit rather than covert.

Figure 3 summarizes this assessment landscape. Tasks that are shallow and easily outsourced sit in the upper left, providing weak evidence of understanding. Moving rightward increases cognitive depth, while moving downward strengthens verification. The most durable forms of assessment lie in the lower-right quadrant, where students must model, critique, and justify their thinking in real time. The point is not to eliminate AI, but to shift assessment toward forms where judgment, not answer production, becomes the primary signal of learning.

Ultimately, the goal should not be to simulate a world in which AI does not exist, but to ensure that students develop durable reasoning skills within a world where it does. Physics depends on modelling. Real problems require selecting assumptions, identifying scales, and deciding which effects can be neglected. In some sense, these un-verifiable tasks are a more accurate representation of physics than the neat reproduction of a textbook calculation.

What Do We Want Students to Learn?

It is tempting to ask which tasks AI cannot yet perform, but this framing will age poorly as capabilities change. A more stable question is what we want students to gain from studying physics. Do we value the speed of calculation, or the capacity to model, approximate, and question?

Noticing when a result violates physical intuition requires experience and reflection. Revising a model when assumptions fail requires flexibility. These skills prepare students for research, industry, and public life. If answers become cheap, modelling and critical evaluation move to the foreground. When the answer is free, understanding becomes the scarce resource and the opportunity exists to design learning environments where reasoning cannot be separated from explanation. ■

About the Author

Will Yeadon is an Assistant Professor of Physics at Durham University. His research examines the impact of generative artificial intelligence on physics education and assessment. He holds a PhD from the University of Sheffield, where he developed a novel computational fluid dynamics model for ultra-thin welding processes.

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ILLUMINATING THE PAST: THE ROLE OF OPTICAL IMAGING IN THE INTERDISCIPLINARY STUDY OF MEDIEVAL MANUSCRIPTS

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Optical imaging methods play a central role in the study of manuscripts, from digitization, digital image processing to multispectral and hyperspectral imaging, the latter extending into the domain of spectroscopy. Their non-invasive nature and strong diagnostic potential make them valuable, especially when integrated into an interdisciplinary workflow that guides the selection of areas to be analyzed and supports the data interpretation.

Illuminated manuscripts

The image of monks and nuns painstakingly copying words in solitude is inextricably linked to the Middle Ages. In illuminated manuscripts, this laborious work was elevated to an artform through miniatures, decorations, pigments, gold and silver.

These precious and unique historical documents reflect the craftsmanship of several specialized artisans, influenced by traditions and geographic area. Using a multi-analytical and multi-disciplinary approach, their study connects complementary perspectives from the textual and visual content, providing insights into the cultural context, artistic techniques, workshop practices and trade networks [1-6].

From Point Analysis to Imaging: The Role of Optical Techniques in Manuscript Studies

The analytical study of illuminated manuscripts relies mainly on non-invasive techniques to avoid sampling. Manuscripts are also sensitive to light, humidity, temperature fluctuations, and handling, so contact-based techniques are often restricted, while the use of illumination sources requires a risk assessment irradiation condition, including intensity, exposure time and spectral range. Moreover, in situ measurements are typically preferred, as the transportation of manuscripts is technically and administratively challenging.

Point-based methods such as Raman, Fiber Optic Reflectance Spectroscopy (FORS), Fourier Transform Infrared Reflectance Spectroscopy (FTIR), and X-ray fluorescence (XRF) are widely used to identify pigments, inks, and other materials [1-3]. However, because they probe only selected spots, they cannot fully represent the heterogeneity of manuscript surfaces. Scanning methods, *e.g.* macro X-ray fluorescence (MA-XRF), extend the analysis areas, but require more complex setup and longer acquisition times [2].

In this framework, optical imaging is particularly attractive, enabling non-contact acquisitions over extended areas, often with portable and rapid setups options.

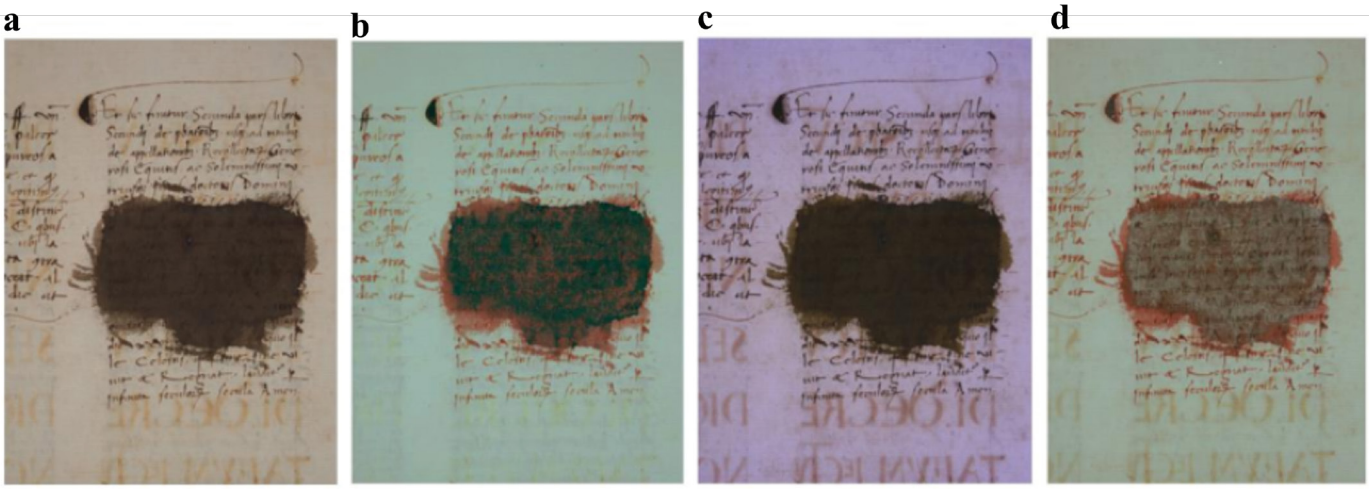
The digitization of manuscripts using high resolution RGB images is a widespread application of optical imaging. Large-scale digitization campaigns led by libraries and cultural institutions are creating digital archives that support accessibility and long-term preservation. Beyond documentation, this process paves the way for digital image processing: mathematical methods have been successfully demonstrated for digital restoration, enhancement, and visualization of miniatures [4], while machine learning methods are being explored for text analysis and pattern recognition [5].

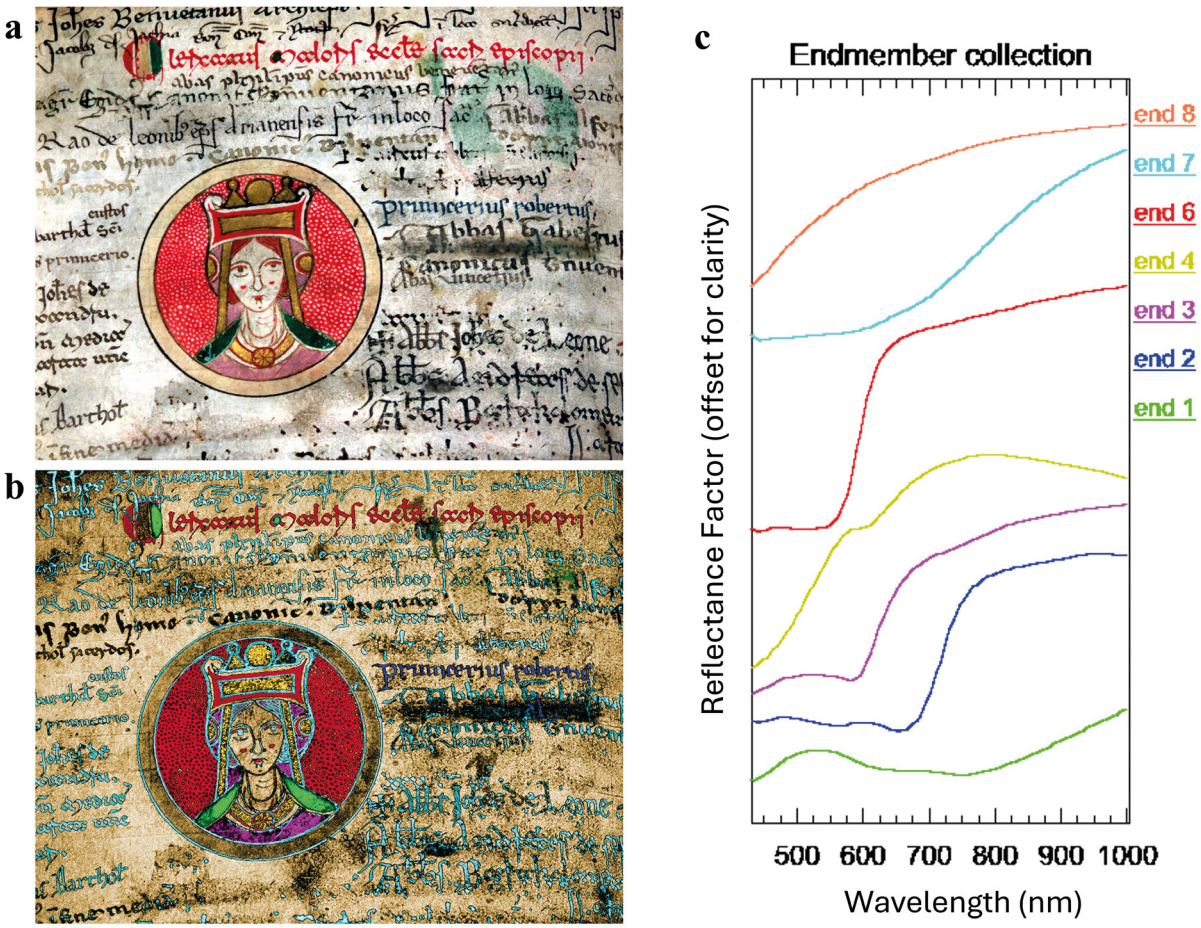
Exploring other regions of the electromagnetic spectrum, UV-induced fluorescence imaging is effective in revealing restorations, degradation products, and organic colorants that would otherwise be difficult to distinguish visually, while infrared (IR) imaging enables the visualization of underdrawings, faded or erased text, and of the *scriptio inferior* in palimpsests [5-6]. A typical multispectral approach exploits the spectral differences between materials, elaborating false color composites, difference images, or principal component images to enhance the visualization of specific features. Fig. 1 illustrates this strategy on the crossed-out colophon of manuscript VII.D.71, listed in "Manoscritti datati del Sud: inventario, p. 90 n. 289" [6]. The figure shows different imaging modalities: visible, IR false colour (IRFC), UV false colour (UVFC), and a composite image, obtained as a linear combination of the previous ones, where the deleted text is readable.

Further extending the acquisition to quasi-continuous spectral bands, hyperspectral imaging (HSI) enables the collection of a full reflectance spectrum for each pixel, generating a three-dimensional data cube (x, y, λ) that combines spatial and spectral information [3]. In manuscript studies, HSI in the VIS-NIR range is used to discriminate pigments, inks, parchment features, underdrawings, and erased or overwritten texts. It merges the benefits of spatial covering of imaging with the spectral discrimination power of spectroscopy, enabling materials to be mapped and, to some extent, identify materials over extended areas.

However, the data interpretation is not trivial. Data quality may be affected by illumination non-uniformity, detector response variability, and optical constraints, leading to striping or shading. Moreover, the measured reflectance, related to the optical properties of materials, is also influenced by factors such as surface roughness, parchment translucency, scattering ● ● ●

▾ **FIG. 1:** (a) Visible image of manuscript VII.D.71, reproduced from Manoscritti datati del Sud: inventario (p. 90, no. 289); (b) false-color infrared image (c) falsecolor reflection ultraviolet image (d) composite image integrating multi-spectral data to improve the readability of the deleted colophon [6].





▲ **FIG. 2:** (a) RGB image of the Folio 90 verso reconstructed from the 642 nm, 541 nm, and 460 nm bands of the hyperspectral datacube; (b) Spectral Angle Mapper (SAM) classification map obtained with the Spectral Hourglass Wizard routine; (c) endmembers extracted by the Spectral Hourglass Wizard, displayed in ascending order: copper green, indigo blue ink, red lake, gold, cinnabar, black ink, and parchment. Reproduced by permission of Ufficio diocesano per la Cultura e i Beni Culturali, Arcidiocesi di Benevento.

effects, and illumination geometry. Thus, careful calibration is required to convert raw data into reliable reflectance values. In addition, the high dimensionality of hyperspectral datasets requires dedicated strategies for data analysis. Chemometric methods such as principal component analysis, spectral angle mapping, and spectral unmixing are commonly used to enhance spectral differences and classify materials, aiding data interpretation. Since each pixel typically contains a mixture of materials (*e.g.*, pigments, binders, substrate), the data are frequently interpreted based on *endmembers*, representative spectral signatures of pure or dominant materials. From them, mixed pixel spectra can be modeled as combinations of a limited number of components.

Spatial and spectral resolution, both desirable for different analytical purposes, are in a trade-off for fixed acquisition conditions [3]. Moreover, their improvement is typically related to longer acquisition times, which cannot be overlooked: faster systems reduce manuscript exposure to artificial illumination and motion artifacts, while increasing the number of objects that can be examined in a limited timeframe.

It is also important to emphasize that in situ work in a library environment imposes significant practical constraints. While high-end laboratory systems offer excellent spectral resolution and broader wavelength ranges, they are typically difficult to deploy in confined spaces. Conversely, compact and lightweight devices come at the cost of performance. For instance, snapshot cameras provide speed and portability but suffer from fewer spectral bands and lower signal-to-noise ratios.

As a result, hyperspectral imaging always involves a compromise between spectral performance, spatial resolution, field of view, acquisition time, and portability.

Case study: "Obituario di Santo Spirito", from Biblioteca Capitolare in Benevento, Italy

Manuscript 28 of the Chapter Library of Benevento (BCB) preserves the obituary and the register of the city brotherhood of the Holy Spirit, written in beneventan script and presented in April 1198 [7]. It documents the effective association in Benevento of secular clergy and lay members for spiritual safeguarding of the community. [8] Its definition, Obituary, is due to the latin verbal

form obit (*i.e.* 'died'), present at the beginning of each death recording. The *Obituary* contains valuable full-page miniatures (fols. 51v-52r, 53v-54r). The codex, now restored, is composed of 109 parchment leaves (263 × 185 mm), bound in pasteboard and brown leather. [7]

Fig. 2 reports the results from the application of Vis-NIR HSI to the Folio 90 verso, which includes both a figurative detail and adjacent written text (Fig. 2a). A portable Vis–NIR system (HERA, 400–1000 nm, NIREOS S.r.l.), based on a Fourier-transform architecture with a common-path birefringent interferometer and a monochrome CMOS detector, was employed. This configuration is compact, lightweight and stable against vibrations, and its spectral resolution is sufficient to enable pigment discrimination.

The instrument was mounted on a tripod and operated with a portable and flexible illumination setup consisting of two halogen lamps and four UV LEDs. Hyperspectral cubes were captured in 10-30s (exposure time of 45ms, two averages per frame), with a single acquisition covering, when necessary, a whole folio.

Calibration included flat-field correction using a white cardboard sheet (A3, 250 g/m^2) and radiometric correction based on dark and white references (Spectralon, Labsphere).

Post acquisition, the data cubes were analyzed in ENVI. Noise reduction was performed using a Minimum Noise Fraction (MNF) transformation [9], followed by the Spectral Hourglass Wizard routine [10] to extract endmembers and classify pixels (Fig. 2b) through the Spectral Angle Mapper (SAM) algorithm, with a tolerance angle of 0.15 rad.

The analysis identified eight spectral endmembers (Fig. 2c), allowing preliminary observations about the pigments and inks nature and distribution. One endmember (end 6) corresponds to cinnabar, showing the characteristic transition edge at 598 nm, while an endmember related to blue indigo-dye ink (end 2) mapped in a single written name ("primicerus robertus"). The black ink (end 7) could not be unambiguously assigned: it possibly represents iron-gall or carbon-based ink, with spectral variations likely due to aging rather than material differences. Gold (end 4) was localized in decorative elements, likely applied as powder with a mordant, and the green areas corresponded to a copper-based pigment (end 1). The pinkish areas proved more challenging to interpret and may be associated with the use of a red lake (end 3). The spectral response of such materials can vary significantly depending on dye concentration, particle size distribution, and the nature of the metal–dye complex, leading to poorly distinctive spectral features and reduced diagnostic specificity, which complicates unambiguous identification. As expected, this folio shows different inks and marks of erased text, suggesting that it was used at different times to record multiple entries. These features make it a rich case study for exploring both the palette and writing practices employed over time.

No man is an island: the necessity of a collaborative approach

Although informative, optical imaging cannot answer all the research questions raised in the study of illuminated manuscripts. Even when imaging and spectroscopy are combined, as in HSI, the integration with additional analytical techniques is a necessity. This practice, common in heritage science, requires coordination not only between disciplines, but also between different instrumental approaches, acquisition times and logistical constraints.

The Beneventan case of study was carried out within a broader MOLAB campaign [11], part of E-RIHS, the European Research Infrastructure for Heritage Science, which provides portable analytical instrumentation for in situ studies of heritage objects [3,11]. Held at the Biblioteca Capitolare in Benevento, the campaign focused on a variegated collection of 12th-century manuscripts associated with local scriptoria. The main aim was to assess whether manuscripts produced in the same cultural and geographical context shared common materials and techniques, or whether significant differences could be identified among production centers. To address this question, folios from four manuscripts, including hagiographic lectionaries, breviaries, and an obituary, were examined over three days, integrating hyperspectral imaging with point-based techniques such as FORS, FTIR, and Raman spectroscopy.

Within such articulated multi-analytical campaigns, workflow optimization is essential. Imaging methods are often the first investigative step, as they rapidly provide spatially resolved information, guiding the selection of representative locations for subsequent point analyses. In our case, HSI was used in this capacity, exploiting its rapid spectral mapping capabilities to identify regions with distinct spectral features. Moreover, the hyperspectral measurements provided a preliminary characterization of the manuscript palette: similar sets of endmembers were found across the examined manuscripts, suggesting shared materials and techniques within the Beneventan production context.

Overall, this study confirms the value of hyperspectral imaging both as a stand-alone technique and as part of a broader multi-technique framework, where it demonstrates the ability to guide, connect, and enhance the wider analytical process.

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Teresa Cacace is a physicist specializing in optics and coherent imaging, with expertise in non-invasive diagnostics for cultural heritage, currently working at the Institute of Heritage Science (CNR).

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Antonino Zichichi - (1929-2026)

Antonino Zichichi, an influential and leading figure in high energy particle physics, passed away on 9 February 2026 at the age of 96.

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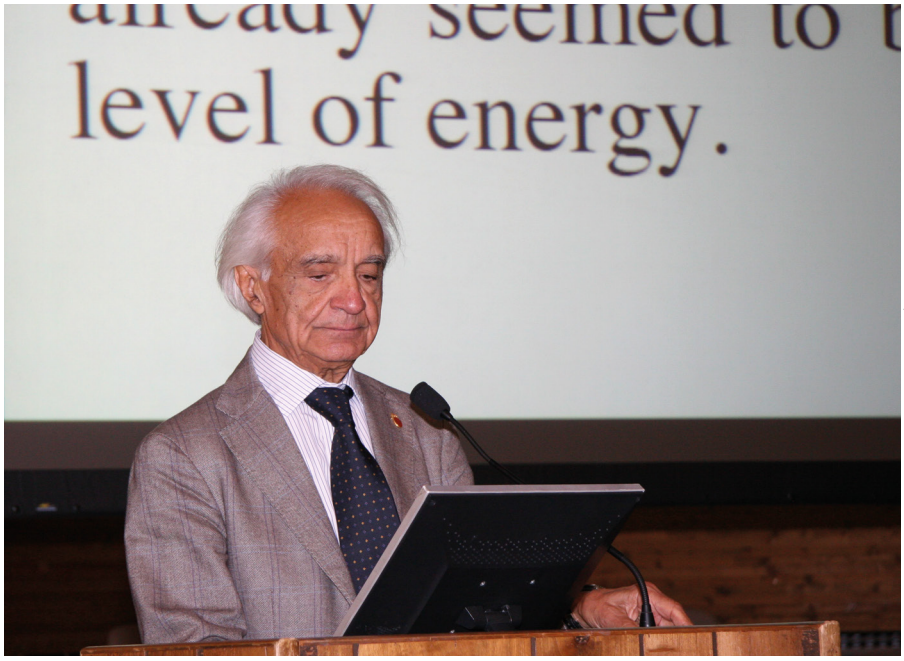

Professor Emeritus at the University of Bologna, Member of the Pontifical Academy of Sciences, the Academia Europaea and the Academy of Sciences of the Institute of Bologna, and founder of the "Ettore Majorana" Centre for Scientific Culture in Erice, he held numerous prominent roles in the international scientific community. These included President of the Italian National Institute for Nuclear Physics (INFN), the European Physical Society (EPS), the World Federation of Scientists, the World Laboratory, and the "Enrico Fermi" Historical Museum of Physics and Study and Research Centre (Centro Fermi/CREF). Founding member of the EPS in 1968, he served as its 5th President in the years 1978-1980.

The conception and creation of the INFN Gran Sasso National Laboratories are credited to him. His contributions and decisive drive were also fundamental to the realization of major particle accelerators, such as LEP and LHC at CERN, and HERA at DESY. His visionary project for a proton supercollider, named ELOISATRON and proposed in the late 1970s, has anticipated the LHC at CERN as its first phase and foreshadowed the Future Circular Collider (FCC) project, an integral part of CERN's strategic plan for the coming decades.

A true promoter of cutting-edge experimental research at the laboratories of Frascati, CERN, DESY, and Gran Sasso, he and his team achieved fundamental results in nuclear and subnuclear physics. These include the discovery of the antideuteron —the first example of nuclear antimatter— the discovery of new phenomena in QCD (such as the *leading effect* and *effective energy*), and the evidence for the first beauty baryon. He also established significant limits on free quark production in strong and weak interations, and on heavy lepton (τ) production in e^+e^- collisions, the existence of which he first proposed, developing and testing a new method to search for it, which then led to its actual discovery.

Furthermore, he pioneered original particle detection techniques, such as the preshower in calorimetry, and achieved intense R&D for new detectors within the framework of the CERN LAA project. Notably, he led the development of novel microeletronic chips and of the Multigap Resistive Plate Chambers (MRPCs) for measuring particle time-of-flight with record precision; these devices still constitute the large TOF apparatus for particle identification of the ALICE experiment.

His commitment to disseminating scientific culture was remarkable, innovative, and of immense scope, spanning articles, interviews, television appearances, seminars throughout Italy and beyond, and numerous books for a general audience on major themes and figures of physics.

As for dissemination, it is worth mentioning the unique and still ongoing EEE project he has launched in 2004 at Centro Fermi and successfully expanded over the years. This is a true astroparticle physics experiment carried out through a network of muon telescopes (each made up of three layers of MRPCs) installed in more than 50 high schools throughout Italy and all connected to the INFN CNAF computer centre. Together, these telescopes form an unprecedented observatory that combines teaching and research in physics, involving hundreds of students every year.

His leadership in international collaboration for the study of planetary emergencies, advocating for a science without secrets or borders, leaves an indelible mark on the scientific community. The Erice Statement, which he co-authored in 1982 with Nobel Laureates Paul A. M. Dirac and Piotr Kapitza, remains a milestone in the quest for a peaceful future in the face of ongoing nuclear proliferation threats.

With the passing of Antonino Zichichi, we lose an eminent figure in contemporary science and a key player in physics at the turn of two centuries. We also lose an outstanding mentor who always offered great opportunities to all those who had the privilege of working with him and whose legacy will live on for future generations. ■

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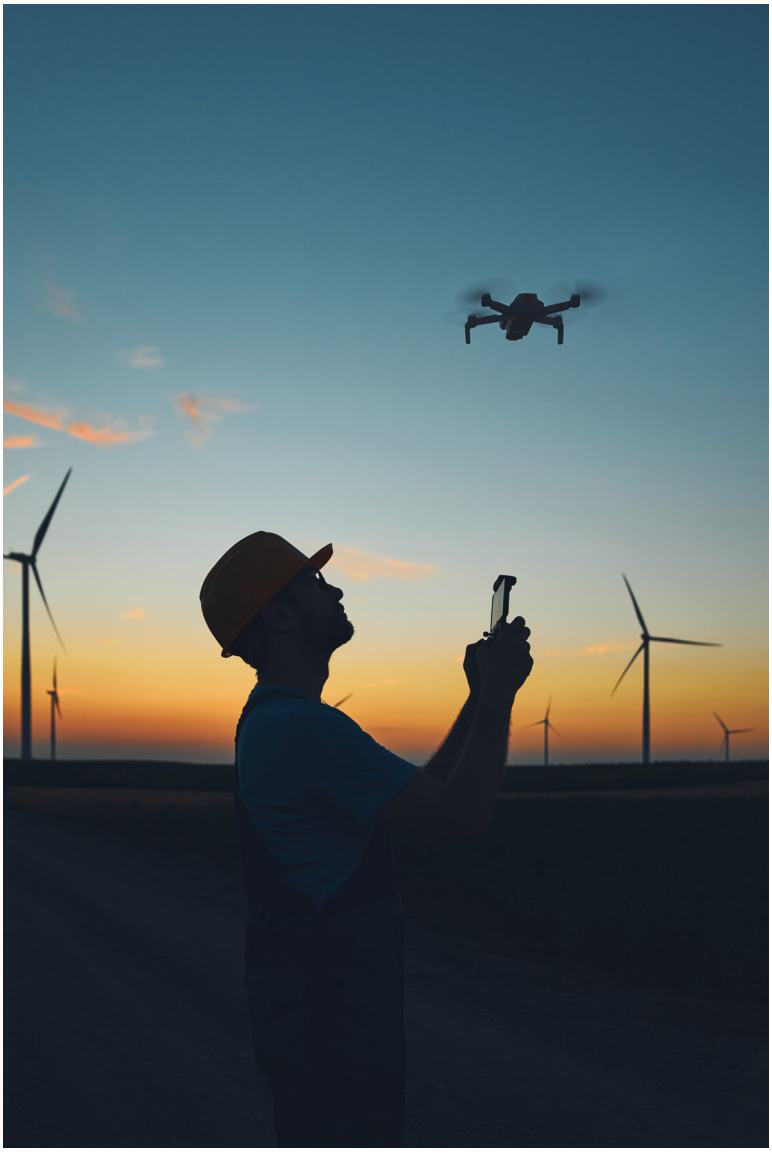
In the next EPN issue

The upcoming issue of EuroPhysics News will explore the rapidly evolving world of drones, highlighting their growing impact across science, technology, and society. This edition brings together cutting-edge perspectives on emergent dynamics in drones, examining how complex collective behaviors arise in multi-agent systems, alongside insights into the design of autonomous drones, where advances in control, sensing, and artificial intelligence are pushing the boundaries of independence and reliability.

The issue also delves into social learning and drones, an emerging field investigating how drones can adapt through interaction and shared information, opening new avenues for collaborative intelligence. Finally, a broad overview of the applications of drones showcases their transformative role in areas ranging from environmental monitoring and disaster response to industry and healthcare, offering readers a comprehensive look at both current capabilities and future directions.

Stay tuned for a deep reading of EPN 57/3, on-line around 26 June 2026 as a flipbook at epn.eps.org and as registered document at europhysicsnews.org. ■



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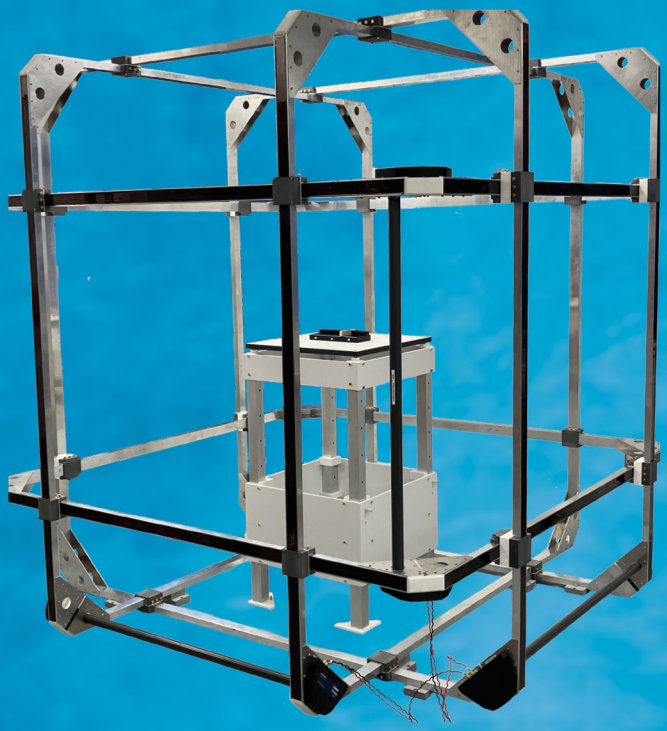

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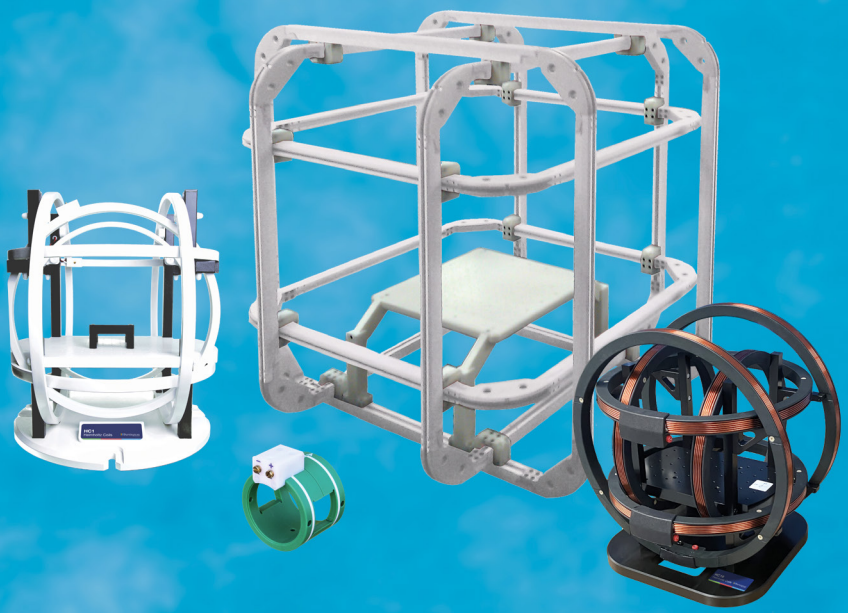

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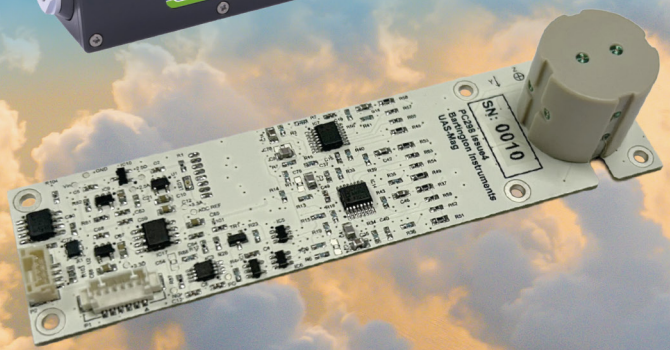

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